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Monterey, California

THESIS

NUMERICAL ANALYSIS OF THE ELASTIC SHOCK RESPONSE OF SUBMARINE INSTALLED EQUIPMENT

by

Mark Steven Welch

September 1984

Thesis Advisor: Y. S. Shin

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Motivated by a lack of explosive test data on nuclear submarines, the Navy has sought other means to qualify installed equipment in submarine shock environments. The currently used method for non-shock testable items is the Dynamic Design Analysis Method (DDAM) developed by the Naval Research Laboratory in the early 1960's. With the advent of large-scale computing power, newer numerical methods have become

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Numerical Analysis of the Elastic Shock Response of Submarine Installed Equipment

by

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Lieutenant, United States Navy
B.S., University of Michigan, 1978

Submitted in partial fulfillment of the
requirements for the degree of

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September, 1984

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I. INTRODUCTION

A. BACKGROUND

Modern combat vessels must be designed with the capability to survive moderately severe shock loadings induced by the underwater explosion of conventional or nuclear weapons. In the scope of this investigation, survival includes the mission survival of the platform. It must maintain its ability to utilize all machinery and weapons systems to carry out its primary mission following an underwater explosive attack. Although the vessel may withstand considerable hull damage and maintain its structural integrity, failure of internal equipment can render it useless as a weapon and thereby eliminate its value in time of crisis. This investigation examines the shock loading of internal equipment in submarines and some of the methods available to analyse shock response.

In view of the fact that a submarine can not be expected to survive a direct hit by any modern, high-intensity weapon, many attempts have been made to specify a level of shock loading for the purpose of design evaluation. The current specifications for building submarines contain the shock requirements to be met by the builders and vendors of installed equipment. Generally, all equipment is to pass a series of shock tests, in the installed configuration as outlined by MIL-S-901C [Ref.1], where shock testing is practical. This document specifies standard explosive and mechanical test fixtures and procedures for conducting the tests. The suitability of an equipment design or installation is evaluated according to its ability to function as intended during and after each shock impulse. Equipment testing is very expensive and requires a great deal of preparation. In the case of equipment design, it is often not practical to evaluate an installation prior to the final design. In some instances, the direct testing of installed components may not be possible from the aspect of prohibitive size or weight. In these cases, a design analysis is specified.

The design analysis for shock response was first proposed in the United States during World War II. Hull damage reports indicated the degree of suceptibility of installed equipment to shock loadings from bombs and depth charges. Based on limited testing and observations, a shock design factor was specified. A series of curves were used to depict the variation of shock design factor with equipment weight to yield an equivalent static design force. This force was used to specify mounting hardware and main structural members for the equipment installation and varied with motion input direction. The method proved to be simple in application but reflected a lack of realism with experimental tests.

In the late 1950's, nuclear power plants were incorporated into submarine designs to afford them greater independence from the frequent surfacing requirements inherent in conventional submarine operations. Nuclear power plant technology was new and thus had no previous history of shock resistance. The acquisition cost of nuclear components is high and the new dangers associated with their damage from underwater explosion sparked a renewed interest in underwater explosion testing and design analysis. From the late 1950's through the middle 1960's, most of the currently used standards for submarine-installed equipment shock design were adopted.

The Dynamic Design Analysis Method (DDAM) was proposed by the Naval Research Laboratory and accepted by the Navy as a design evaluation requirement in 1963 [Ref 2]. The details of this specification will be discussed more fully later; however, the basic principle is stated here. DDAM is a simplified modal analysis method which utilizes shock inputs which were empirically derived from underwater explosion tests of realistic ship and submarine installations. It is assumed that the equipment and its foundation together make up a system which responds as a linear elastic structure to the input which is described by a design shock spectrum. The successful utilization of DDAM to evaluate equipment response to a design shock input is dependent on the ability of the design shock spectrum to reflect accurately the structural environment existing in a given installation. This will be influenced by the size and weight of the submarine test subject, the structural system employed in the construction of the submarine, and the interaction between the equipment, foundation and hull structure used to derive the design shock spectrum.

B. THE STATE OF CURRENT SHOCK DESIGN ANALYSIS

Since its adoption, DDAM has been used without modification to qualify ship and submarine equipment installation designs. The original design shock spectrum [Ref. 2] remains intact without revision. Shortly after the adoption of DDAM as a design requirement, underwater explosive testing of nuclear submarines was banned due to the inherent risks involved. This ban was relaxed in 1983 for the low level explosive test of a SSN 688 class submarine. Mechanical and explosive tests of equipment installations on shock simulation platforms are the only regular check of designs meeting the standards imposed by DDAM. A danger exists with this kind of verification in that the tests may be designed to accurately reproduce the input motions provided for in the design shock spectrum utilized with DDAM.

In recent years the increasing availability of large computers and the rapid development of numerical methods have provided the engineer with new tools to use in the analysis of submarine shock response problems. Finite-Element/Finite-Difference methods allow for the analysis of structure and fluid responses and the work of Geers [Ref. 3] provides a means to incorporate fluid-structure interaction effects. Several computer codes have been developed to analyze installed equipment response to shock waves based on these formulations. One of them is the Elastic Shock (ELSHOK) code developed by Weidlinger Associates under Defense Nuclear Agency and Office of Naval Research funding [Ref.4]. The motivation for this work has been to investigate modern submarine underwater explosive shock response in conjunction with a testing program using small to large scale models and shaped, explosive, tapered charges. Throughout its development, ELSHOK has been validated using these highly controlled tests. In the low level explosive test of the SSN 688 class submarine, ELSHOK was used to predict the level of equipment responses prior to the tests and to increase the level of confidence associated with the tests. This code has now been made available to the Naval Postgraduate School by the Defense Nuclear Agency along with support from Weidlinger Associates.

C. PURPOSE FOR THIS INVESTIGATION

DDAM is a design tool. Its function is to provide a numerical method by which the engineer can check his design as to its adequacy for installation in a submarine. It is intended to be conservative and straightforward to apply. When DDAM was first proposed [Ref.4], its authors warned that the design shock factors specified [Ref.2] were not absolutely determined and should be reviewed as explosive testing progressed and data was accumulated. Although testing procedures for installed equipment components have become very sophisticated, these simulators may not accurately reflect the response of installations in modern day submarines. Without the ability to carry out high-intensity shock tests on real submarines, verification of the design shock spectrum used in DDAM can not be accomplished as intended. The evolution of numerical codes capable of simulating the response of installed equipment to a specified shock loading makes available a means to check the applicability of the originally proposed design shock factors provided in DDAM to modern submarines. There is no flexibility built into DDAM to allow design for other than the originally prescribed shock input magnitude. DDAM makes no separate account for equipment/structure interaction effects.

The purpose of this investigation is to examine the response of several equipment models installed in a present day scale, 6900 long ton (LT) submarine using DDAM and ELSHOK. The equipment models range in weight from 1,000-20,000 pounds. Simple models are used to make correlations possible between the two methods and worst case results are obtained. Additionally, equipment/hull interactions are investigated for their possible influence on overall equipment response.

II. DYNAMIC DESIGN ANALYSIS METHOD

A. DESCRIPTION OF DDAM

As mentioned in the introduction, DDAM is a simplified modal analysis method which utilizes shock inputs which were empirically derived from underwater explosion tests of realistic ship and submarine installations. Although the analysis is identical for both types of vessels, all references in this document will be to submarines. In order to utilize DDAM to evaluate a design, several assumptions must be satisfied.

1.) The equipment and foundation make up a linearly elastic system.

2.) The structure can be represented reasonably well using a lumped parameter model.

3.) The structure is hard mounted to the rest of the submarine. No bottoming, or damped mounts are allowed.

In Navy shock requirements, equipment shock classifications are based on a graded system. These grades run from A for mission critical items, to C for items that could indirectly affect the ability of the vessel to function as intended. For instance, a locker which becomes adrift and could injure personnel or surrounding equipment could be grade C. The grade of the item is specified by contract and determines the degree of shock qualification it must undergo to be considered safe for installation. In this study, all equipment models were considered grade A.

The ideal way to compute the elastic shock response of an installed equipment is to consider the entire structure (submarine and equipment) as an elastic system. The normal modes and natural frequencies of this system can then be determined and the response of each normal mode to the water applied pressure loadings computed. The modal responses can then be superimposed to get the resultant equipment response. In an everyday design method such as DDAM, this approach is impractical. To simplify the above procedure, DDAM utilizes the concept of a shock spectrum. Any point on the complete structure can be designated as a reference point which can then be considered to be a fixed base for the equipment on one side of it. The dynamic response of this portion can then be computed by superposition of normal mode responses to the motion of the fixed base. In DDAM, this motion is specified as a step input to each normal mode and is calculated by empirical equations based on underwater explosion tests of models and submarines [Ref. 5]. A detailed treatment of the mathematical basis for DDAM is given by Butt [Ref. 6].

In order to use DDAM, a lumped parameter model of the equipment must be formulated to obtain the matrix expression:

$$[M]\ \{\ddot{X}\} + [K]\ \{X\} = \{0\} \qquad (1)$$

which has the associated eigenvalue problem

$$[M]\ [X_{ia}]\ [\ \omega^2\ ] = [K]\ [X_{ia}] \qquad (2)$$

where $[X_{ia}]$ is the matrix of eigenvectors and $[\omega^2]$ is the diagonal matrix of natural frequencies. The advantage of this procedure is that it allows uncoupling of the equations of motion and subsequent solution of the dynamic problem in terms of its component modes. Careful formulation of the equations of motion to capture all the dominant characteristics of the equipment leads to good results with only a small number of modes. When DDAM was developed, it was intended to be used primarily in hand computations. The major difficulty encountered in the use of DDAM was the solution of the eigenvalue problem which can readily be handled today with small computers. The normal mode theory upon which DDAM is based is well established in shock and vibration practice. The area of concern is the adequacy of the adopted design inputs to reflect present day submarine building practices.

B. DESIGN SHOCK INPUTS

The specification of design shock inputs for use in DDAM calculations determines the usefulness of this method in the evaluation of equipment installation designs. DDAM is a standard. The design input values must provide consistent fixed-based equipment excitations for the broad base of submarine platforms in use today to simulate a "standard" underwater explosion. To simulate this requirement here, charge weights and standoffs were selected so that each case corresponded to a constant value of energy flux density; i.e.,

$$W/R^2 = \text{Constant} \qquad (3)$$

In this equation, W is the equivalent weight of the charge in pounds of TNT and R is the standoff distance from the hull in feet. The submarine platforms in use today range in size from about 4,600-18,700 LT. Each submarine hull is characterized by its own modal properties (mass distribution, natural frequencies, mode shapes). The same piece of equipment as is installed in a small submarine will demonstrate a different response when installed in the same configuration, in a large submarine. The effect of hull/equipment interaction becomes an important consideration in large pieces of equipment tuned to one or more natural frequencies of the hull structure. The design shock input used with DDAM must incorporate these factors so that when it is said that a piece of equipment meets the specification for qualification, the qualification level is the same for all submarine classes.

In the publications regarding DDAM, little is said about the origins of the particular shock input spectrum utilized to evaluate equipment response. It has been empirically derived to provide values consistent with the data upon which it is based. In the event that it is decided to design submarines to resist underwater explosions of a different shock intensity than the one chosen for the present method, a major effort would be required to construct a data base upon which to base the new input values.

C. USING DDAM

Since the development of DDAM, new tools have replaced the slide rules of engineers. Among them are the readily available desktop computers. In the course of this work, it was necessary to use DDAM to analyse simple structures of fewer than 50 degrees of freedom. To this end, a computer program has been written in the BASIC computer language to carry out the required computations. A listing and short users' manual can be found in Appendix A. The program was verified by comparing results with hand calculations and published sample problems.

III. EXPLOSIVE SHOCK RESPONSE ANALYSIS USING ELSHOK

A. GENERAL PRINCIPLES OF OPERATION

The ELSHOK computer code [Ref. 4] calculates the transient response of a submerged, ring-stiffened shell of revolution, with or without internal structure, to an underwater shock wave emanating from an explosive source placed at an arbitrary location away from the shell. The structure is considered to be linearly elastic, and the surrounding fluid is treated as an infinite acoustic medium. Modal structural analysis is used in all phases of the calculations. Internal equipment response is treated by coupling the free-free modes of the empty ring-stiffened shell and the fixed-base modes of the internal equipment through use of dynamic boundary conditions [Refs. 7,8]. The structure-fluid interaction is approximated by means of the Doubly Asymptotic Approximation (DAA) due to Geers [Ref. 3]. The form of the DAA used is that obtained when the normal fluid displacement of the structure-fluid interface is expanded using surface expansion functions which are orthogonal over the wet surface of the submarine. At frequencies of zero and infinity, the pressure-velocity relations are exact so that in transient analysis, the DAA yields exact results at early and late times, and by the nature of its formulation provides a smooth transition between these two limits. In effect, the DAA allows for uncoupling of the fluid field problem from the structural field problem.

The structural problem solved by ELSHOK is separated into two parts. A modal substructuring procedure is used to solve the dynamic response problem for internal equipment. The advantage of this is to eliminate the need to handle the modes and natural frequencies of the combined structural problem, as well as the requirement for a combined system stiffness matrix. Interaction forces and moments, and compatibility of deformation at the shell-substructure attachment points are used to solve for the dynamic response of the component parts.

Referring to the ideal case of DDAM formulated without the use of a shock input value; ELSHOK is a numerical means to arrive at the input to the substructure without dependence on an explosive testing database and with the added advantage that interaction effects between the hull and substructure are taken into account. ELSHOK performs a transient analysis whereas DDAM utilizes a simplified "front end" to arrive at the maximum forces and deflections in a given response problem for a single magnitude of loading.

B. ORGANIZATION AND IMPLEMENTATION OF ELSHOK

The ELSHOK code is implemented as a series of seven programs. The major components are:

1. BOSOR4 - structural analyzer for shell [Ref. 9]
2. ACESNID - virtual mass processor
3. PIFLASH - shell-fluid processor
4. SAPIV - structural analyzer for substructure [Ref. 10]
5. PICRUST - substructure processor
6. USLOB - time integration processor
7. PUSLOB - plotting processor

Figure 1 depicts the general relationship among the code modules. The numbers above correspond to the chronological execution order to be followed in a given analysis. In order to carry out an analysis using ELSHOK, a lumped parameter model of the submarine being analyzed must be formulated or available as well as the equipment model. More will be said about models later. The computations are carried out in four phases.

B.1. Phase I - Shell and Fluid Analysis

BOSOR4 is a finite difference code used to capture the effects of the submarine hull structure on the overall response. Two models are actually used: a full model containing information about the major configuration

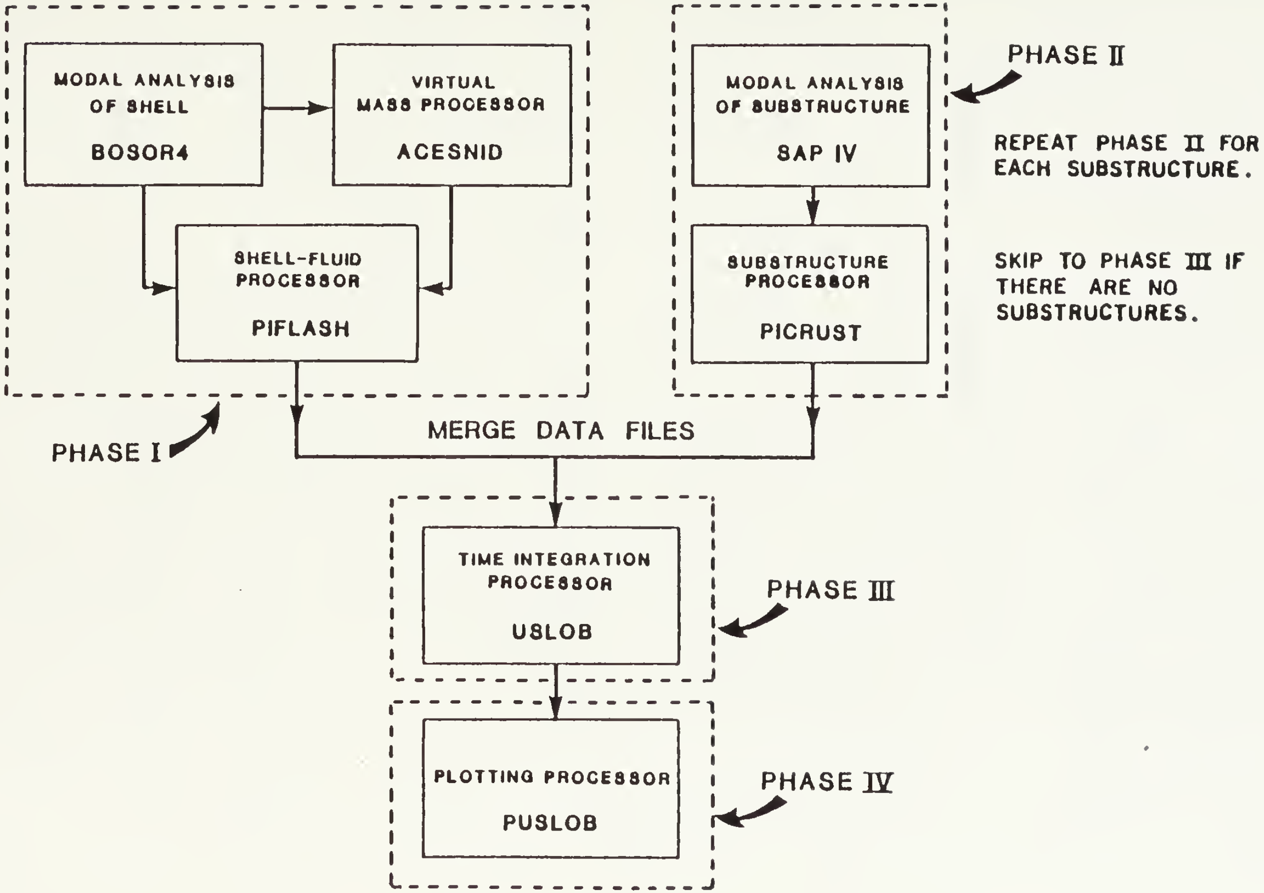


Figure 1 - Organization of the ELSHOK Computer Code [Ref.4]

of the submarine and its general dynamic properties, and a compartment model representing the localized area of interest on the hull. The full model is used to capture the gross effects of the response such as rigid body translation and whipping (N = 1 modes), and rolling and twisting (N = 0 torsional modes) of the entire structure. The compartment model is used to capture local details of the response in the area of interest (N = 0 breathing and N≥2 modes). N is the integral number of circumferential waves or harmonics in the circumferential distributions of the surface expansion functions. For each N, a separate BOSOR4 calculation is required. The BOSOR4 code provides the in-vacuo free-free modes and natural frequencies of the submarine hull.

The second part of phase I is the use of ACESNID to compute the virtual mass array, which is used in the late time contribution of the DAA. The virtual mass array is determined from the solution, based on simple sources, of a steady-state low frequency problem in which normal displacements corresponding to the surface expansion functions are applied to the surface of a cavity of revolution in an infinite fluid having the same size and shape as the wet surface of the submarine. Only one run of this module is required for all values of N considered.

The final step in phase I is the execution of PIFLASH to compile the data from all BOSOR4 runs and ACESNID into a shell-and-fluid file for later use. The analysis done for the work in this thesis considered only the hull response of one submarine so only one shell-and-fluid file was needed for all subsequent calculations.

B.2 Phase II - Substructure Analysis

SAPIV is a commonly available finite element code used in the ELSHOK code to perform the modal analysis of each substructure (equipment model). The equipment installation is first cast into an appropriate finite element representation and then SAPIV is used to solve for the desired mode shapes and frequencies. This information is placed in a substructure mode file along with the geometry, stiffness and mass information. The mass, mode, and frequency information were also used in the DDAM analysis for comparative purposes.

The final step in phase II is the execution of the PICRUST code. This code prepares the input for phase III calculations by placing the above modal information on a substructure file. Additionally, it calculates influence coefficients corresponding to the base or support motions of the substructure and accounts for the user-specified connectivity.

B.3. Phase III - Time Integration

Following the completion of Phases I and II, the shell-and-fluid file is merged with the substructure file to form the input file for USLOB which is ELSHOK's time integration processor. USLOB allows specification of the charge weight and geometry. For the problems of concern here, an exponentially decaying, empirical model was used to represent the explosive shock source. It is of the form:

$$P_I(R) = K_1(W^{1/3}/R)^{K_2} \exp(-t/\theta_0) \qquad (4)$$

where;

$P_I(R)$ = the incident pressure at a radius R from the explosion (on the hull)

K_1 = a multiplicative constant for incident pressure

K_2 = a spatial decay constant for incident pressure

t = time after arrival of shock wave at point of interest

W = weight of spherical charge

θ_0 = $K_3 W^{1/3} (W^{1/3} / R)^{K_4}$

K_3 = multiplicative constant for time constant of exponential decay

K_4 = spatial decay constant for time constant of exponential decay

In all the cases, the geometry was such as to maintain constant energy flux according to eq.(3). The integration in time is done using a modified version of the Runge-Kutta numerical integration scheme. During the integration, USLOB outputs velocity histories for user-specified points on the hull and substructure.

B.4. PhaseIV - Plotting

Phase IV capabilities were not utilized in this investigation. However, ELSHOK does have the capability to generate plot files containing velocity history information for processing on a graphics terminal.

B.5. Deflection Calculations

As mentioned previously, ELSHOK produces velocity histories at the points of interest on the substructure. DDAM produces maximum deflections or forces at the same points for similar models. In order to make comparisons between the two methods, it was decided to convert the velocity histories from ELSHOK to deflection histories using an integrator based on Simpson's 1/3 Rule. For each equipment case, a separate program was written in BASIC to accomodate the variations in configuration between each model and the differences in output from the USLOB code due to point of interest specification. These programs are listed in Appendix B.

IV. MODELS USED IN THE ANALYSIS

A. FINITE ELEMENT/FINITE DIFFERENCE MODELS

The idea of representing a given domain as a collection of discrete elements or values was not first applied in finite element/finite difference methods. Early mathematicians estimated the value of π to nearly 40 decimal places by representing the circle with a polygon of a finitely large number of sides. The polygon used by the mathematicians is a model of the circle they wished to represent. In modern numerical methods, it is realized that very few problems in the real world can be analyzed without the use of simplifying models. BOSOR4, the finite difference code in ELSHOK used to describe the dynamic behavior of the submarine hull, requires a greatly simplified model of its real world counterpart. Similarly, both DDAM and ELSHOK use a substructure model to capture the fixed-base properties of installed equipment.

B. SUBMARINE HULL MODELING USING BOSOR4

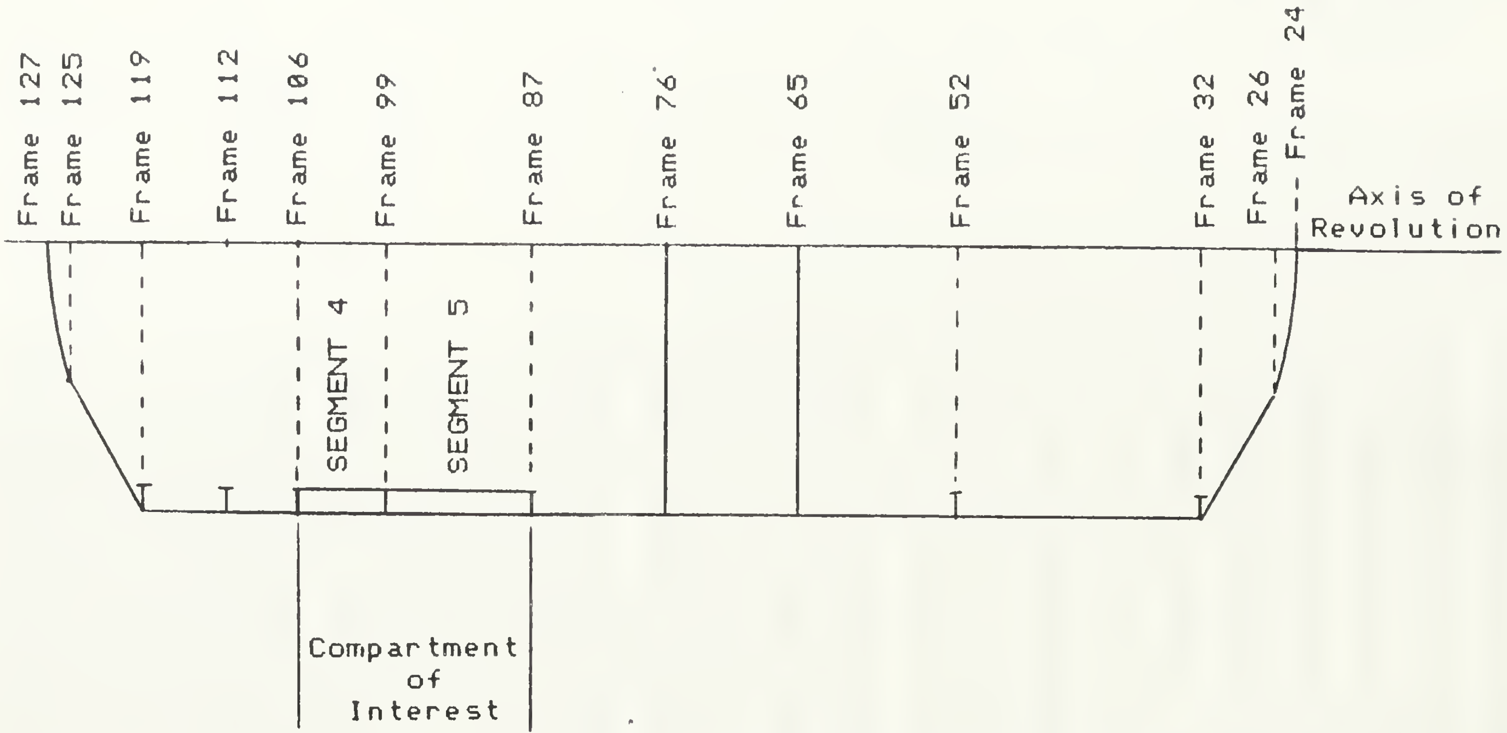
Actual submarine hulls are very complex structures. However, they do possess certain characteristics that can be used to simplify their modeling. From the aspect of submarine hull shock response, the hull is a free-free ring stiffened cylinder with suitable end closures. The internal weights of machinery and other outfitting must be accounted for but these items can be smeared into their adjacent hull structure. The model thus becomes a cylinder whose cross sections reflect the density of the submarine at a given frame. Since a cylinder is a surface of revolution, the properties of each cross section need only be specified at one point. The reader will notice that any hard structure serving to stiffen the hull in a non-axisymmetric sense, such as non-circular frames or massive machinery foundations, can not be represented in this fashion. If these structures are in the area of interest in the hull, they should be modeled as internal structures in phase II of ELSHOK.

The BOSOR4 code allows the submarine hull model to be constructed by specifying the properties of the submarine hull along a line of revolution. A numerical complication enters the problem when dealing with models of submarines because the structure often repeats itself regularly along its axis of revolution. With such a configuration, there are many modes in which the motion of the stiffeners is of small amplitude compared to that of the shell. The bays between the rings vibrate at frequencies which may approximate those corresponding to a simply-supported cylinder of the same geometry as the bay. Multiple or closely-spaced eigenvalues correspond to modes in which one or more of the bays is vibrating while others are unaffected. To avoid eigenvalue difficulties, the prudent measure is to analyse as small a segment of shell as possible in order to avoid numerical difficulties with multiple, or closely-spaced eigenvalues as indicated by Bushnell [Ref. 9]. In submarine shock analysis, the interest is in the gross response contributions of the entire hull to a given section of interest. The authors of ELSHOK have allowed for this through the use of two models.

A full model is used to obtain the gross contributions of the entire hull structure in the N = 0(torsional) and N = 1 (translational and whipping) modes. This will include such things as bulkheads, heavy ring stiffeners, and end closures. A compartment model is then used to obtain more detailed information about the particular section of interest. In this way, responses away from the section of interest do not have to be carried through the remaining calculations since they do not affect the response of this area anyway.

Due to security restrictions placed in information regarding the construction techniques and arrangements of U.S. nuclear submarines, it was not possible to model an actual submarine for use in the analysis work contained in this thesis. With the aid of Weidlinger Associates of New York, however, a model resembling a general submarine hull structure of 6900 long tons displacement was obtained. This model is available through the U.S. Naval Postgraduate School but is not included here so that restrictions do not have to be placed on the circulation of this work.

Figure 2 is a schematic depiction of the full submarine. The submarine being modeled has been cut into 149 slices along the longitudinal axis. In the model, information regarding Young's modulus, Poisson's ratio, mass density, thermal expansion coefficient, plating half-thickness and whether or not stiffeners are smeared is provided for each one of these points. Twenty-six discrete rings are represented along the axis of the model, twenty of which are in the local area of interest. These rings represent frames in the real submarine where T-stiffeners give increased stiffness to the hull. In actuality, these stiffeners are spaced fairly evenly along the entire model, but smearing them outside the area of interest will not appreciably affect the vibrational characteristics in the area of interest. Using the BOSOR4 code, modal analysis using finite difference techniques is carried out. Table 1 is a listing of the natural frequencies and wave numbers for each mode retained in the analysis. Seven N = 0 torsional modes, and thirty-eight N = 1 rigid body displacement and whipping modes have been retained for the full model.



Note: compartment of interest details are the same as depicted in figure 3.

Figure 2 - Full Model Used to Capture Gross Response of Submarine

MODE	N	FREQ (Hz)	MODE	N	FREQ (Hz)
1	1	3.597568E-02	2	1	4.716345E-02
3	1	2.877285E+00	4	1	7.890112E+00
5	1	1.298816E+01	6	1	1.793631E+01
7	1	1.801155E+01	8	1	1.897726E+01
9	1	2.305725E+01	10	1	2.720918E+01
11	1	2.992269E+01	12	1	3.228725E+01
13	1	3.411510E+01	14	1	3.498256E+01
15	1	3.568254E+01	16	1	3.590094E+01
17	1	3.716095E+01	18	1	3.806356E+01
19	1	3.847244E+01	20	1	3.962965E+01
21	1	4.027563E+01	22	1	4.059142E+01
23	1	4.295875E+01	24	1	4.390227E+01
25	1	4.492591E+01	26	1	4.916127E+01
27	1	5.261150E+01	28	1	5.289662E+01
29	1	5.544796E+01	30	1	5.634701E+01
31	1	5.994869E+01	32	1	6.131432E+01
33	1	6.312191E+01	34	1	6.521966E+01
35	1	6.574109E+01	36	1	6.682896E+01
37	1	6.761096E+01	38	1	6.845927E+01
39	0	4.013475E-05	40	0	7.584749E+00
41	0	1.465699E+01	42	0	2.342790E+01
43	0	3.021683E+01	44	0	3.855958E+01
45	0	4.579604E+01			

TABLE I - Wave Numbers and Frequencies of Full Model

Figure 3 is a schematic representation of the compartment (local area of interest) model used in this analysis. In this model, all frames are modeled as discrete ring stiffeners. Since compatibility must be maintained between the two models, (compartment and full), there is a one to one correspondence in the area of interest between points in each model. The compartment model is used to obtain the modal contributions corresponding to N $\geq$ 2 (normal, meridional, and circumferential displacements). As mentioned previously, deformations or motions occuring beyond the region of interest should be unimportant for the N = 0 breathing modes and modes corresponding to N $\geq$ 2. Each bounding ring or bulkhead is very stiff in its own plane and moves primarily in that plane for localized loading. Table 2 is a listing of the natural frequencies and circumferential wave numbers for each mode retained in the analysis. For the compartment model, 25 modes corresponding to N = 2, 24 modes corresponding to N = 3, 24 modes corresponding to N = 4 and 25 modes corresponding to N = 0 have been retained. A total of 254 modes were found by BOSOR4 for the full and compartment models. Of these modes, 143 were retained for further calculations in phase II and III of ELSHOK. The 111 modes that were dropped affect responses primarily outside of the area of interest.

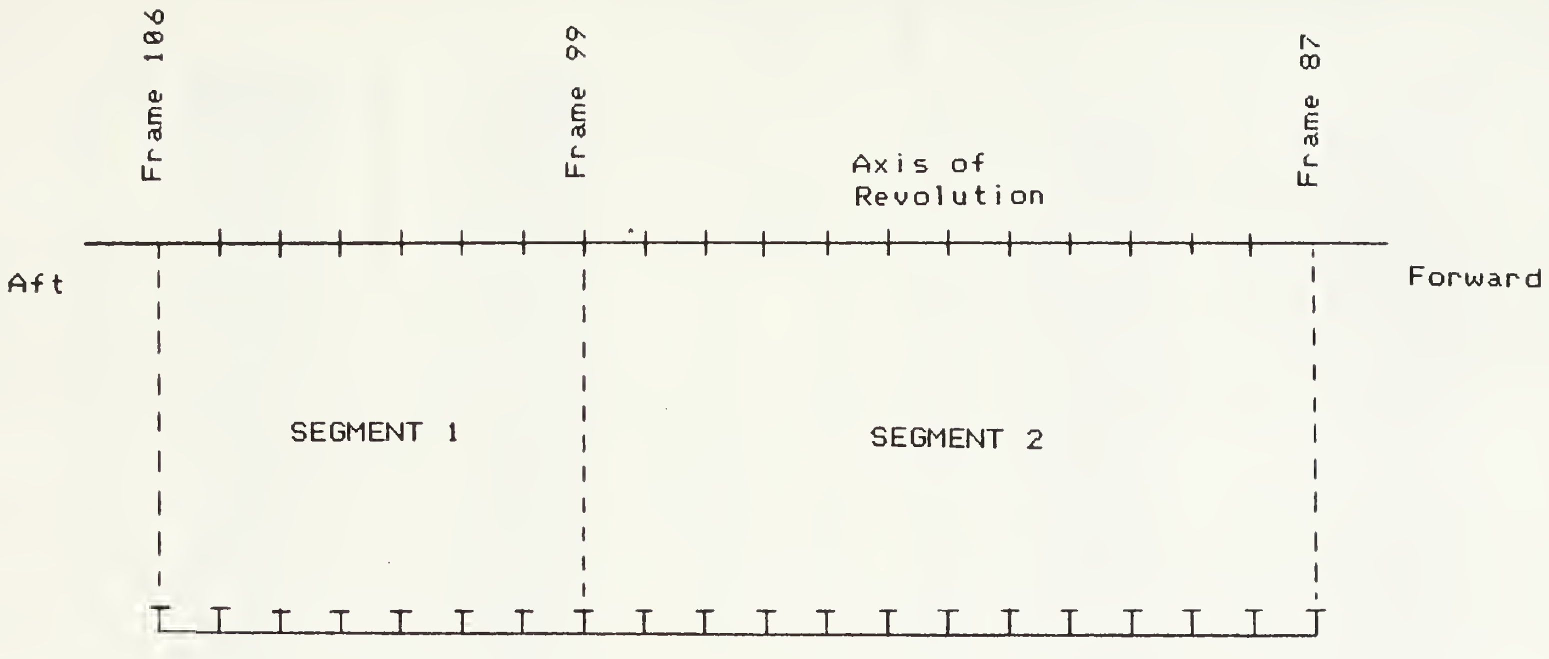


Figure 3 - Compartment Model Depicting Area of Interest
(Note: all major stiffeners included)

MODE	N	FREQ (cps)	MODE	N	FREQ (cps)
1	2	7.468709E+00	2	2	8.734529E+00
3	2	2.348234E+01	4	2	3.479523E+01
5	2	3.630018E+01	6	2	3.915876E+01
7	2	4.066027E+01	8	2	5.381393E+01
9	2	5.852534E+01	10	2	6.621577E+01
11	2	7.125992E+01	12	2	7.204292E+01
13	2	7.573407E+01	14	2	7.843223E+01
15	2	7.850576E+01	16	2	8.092760E+01
17	2	8.341064E+01	18	2	8.354483E+01
19	2	8.646392E+01	20	2	8.778771E+01
21	2	8.886759E+01	22	2	8.989995E+01
23	2	9.272942E+01	24	2	9.475832E+01
25	2	1.007907E+02	26	3	1.813456E+01
27	3	2.555379E+01	28	3	3.064289E+01
29	3	3.538415E+01	30	3	3.965320E+01
31	3	4.383660E+01	32	3	4.571721E+01
33	3	4.761181E+01	34	3	4.934542E+01
35	3	5.352091E+01	36	3	5.896834E+01
37	3	6.117077E+01	38	3	6.686933E+01
39	3	6.961758E+01	40	3	7.115673E+01
41	3	7.465008E+01	42	3	7.683416E+01
43	3	7.795620E+01	44	3	8.125059E+01
45	3	8.312985E+01	46	3	8.451368E+01
47	3	8.721904E+01	48	3	8.895708E+01
49	3	9.991350E+01	50	4	2.483606E+01

MODE	N	FREQ (cps)	MODE	N	FREQ (cps)
51	4	3.166686E+01	52	4	3.371339E+01
53	4	4.384663E+01	54	4	4.852398E+01
55	4	5.246329E+01	56	4	5.753870E+01
57	4	5.839672E+01	58	4	5.986636E+01
59	4	6.132389E+01	60	4	6.295904E+01
61	4	6.489963E+01	62	4	6.722555E+01
63	4	6.812710E+01	64	4	6.924825E+01
65	4	7.073226E+01	66	4	7.251055E+01
67	4	7.376491E+01	68	4	7.659343E+01
69	4	7.834125E+01	70	4	7.971665E+01
71	4	8.213363E+01	72	4	8.386734E+01
73	4	9.928959E+01	74	0	1.334394E-04
75	0	2.776871E+01	76	0	2.999275E+01
77	0	7.198920E+01	78	0	8.395790E+01
79	0	8.436825E+01	80	0	8.450424E+01
81	0	8.483266E+01	82	0	8.531557E+01
83	0	8.574835E+01	84	0	8.648527E+01
85	0	8.669803E+01	86	0	8.724036E+01
87	0	8.797067E+01	88	0	8.884455E+01
89	0	8.973377E+01	90	0	9.051744E+01
91	0	9.190160E+01	92	0	9.246307E+01
93	0	9.479385E+01	94	0	9.507931E+01
95	0	9.559086E+01	96	0	9.873169E+01
97	0	1.012802E+02	98	0	1.027781E+02

TABLE II - Wave Numbers and Frequencies of Compartment Model

Figure 4 is a schematic of the general shell structure model and notation conventions used in the remainder of the ELSHOK analysis. Two coordinate systems are used. X,Y and Z refer to the submarine global coordinate frame and x,y and z refer to the substructure local coordinate frame. In both systems, the x-axes run from aft to forward and the z-axis orientation is related to the Z axis in the global system by the angle α_σ where σ refers to the substructure. The variable s is used to locate points along the meridian of the full model, and u,v, and w are used for local shell displacements and motions located circumferentially by the angle θ. This concludes the discussion of the submarine model used in ELSHOK.

One of the conveniences realized in using a DDAM analysis to carry out design checks is the absence of a submarine model in the computations. The design shock values are intended to provide all inputs to the substructure model. The penalty which must be weighed here is the lack of regard which this places on the peculiarities of a given submarine structure. On the other hand, the ELSHOK submarine model is difficult to construct requiring a great deal of information and skill to properly model a given hull, but the price is paid only once for each submarine class. All subsequent calculations in this thesis are carried out utilizing the same shell model calculations.

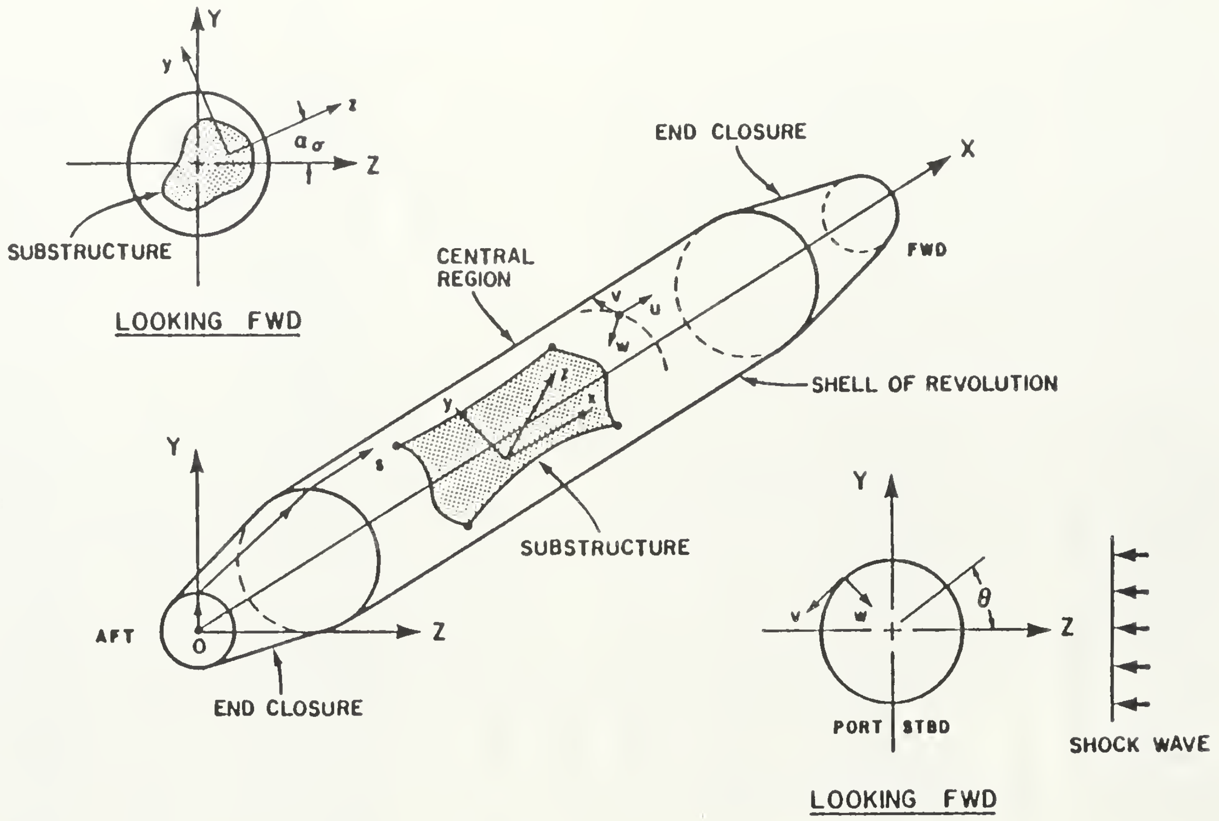


Figure 4 - Shell-Substructure Configuration [Ref. 4]

C. SUBSTRUCTURE MODELING USING SAPIV

In both DDAM and ELSHOK calculations, a substructure model is formulated to determine the modes, masses, and natural frequencies of the equipment system being design checked. When DDAM was first developed, a computer program was available which could solve the eigenvalue problem for up to twenty degrees of freedom. However, the scarcity of computer resources dictated that most users utilize hand computations for this purpose. Consequently, most early design checks were limited in scope. DDAM is well suited to tabular methods of computation but with the common availability of small computers today, hand computations are no longer required, and the restrictions on degrees of freedom are largely removed. This is not to say that great numbers of degrees of freedom are required in every case. By careful examination of the equipment installation being checked, the major response contributions can be captured using a small number of modes. In the cases considered in this thesis, emphasis was placed on using equivalent models for DDAM and ELSHOK rather than closely modeling a real component in a submarine as it would be in each case in actual practice. The interest here lies in how the results compare, for the same models.

Phase II of ELSHOK utilizes the SAPIV finite element code to model submarine-installed equipment. Because

ELSHOK is written utilizing program modules which execute independently and exchange data through output files, the SAPIV code could be used to run the modal analysis of equipment models for DDAM and ELSHOK thus ensuring equivalence in input to both methods. The models selected for analysis were kept small so that comparisons could be made without excessive complication.

Three equipment models have been examined for this thesis. Case I is a cantilever foundation model with a 1000 lb weight attached to its free end. Cases II and III are a simple beam foundation supporting two weights at centerspan and having attachment points on two separate, discretering stiffeners.

C.1. Substructure Case I Model

The case I model development is depicted in figure 5. The model represents a 1000 lb valve supported by a cantilever foundation. The foundation is built up from AISC C 10x30 steel channels [Ref. 11] and the valve is rigidly fixed to the free end. Since the intent was not to qualify any particular valve design, the entire valve has been modeled as a particle (lumped mass). The beam mass is represented by six lumped masses. The foundation is designed to be fixed to a discrete-ring stiffener in the submarine in an upright position. Although 3-dimensional motoion has been allowed, the maximum deflection occurs in the athwartship direction in response to a side-on shock loading. This case is representative of a relatively light equipment installation.

C.2. Substructure Case II Model

The case II model development is depicted in figure 6. The model represents a foundation constructed from AISC W 27x177 I-beams [Ref. 11] supporting two 10,000 lb weights. The foundation structure is represented by 18 beam elements and 19 masses. It spans two discrete stiffeners to which its ends are fixed. This model is representative of a large pump or turbomachinery installation.

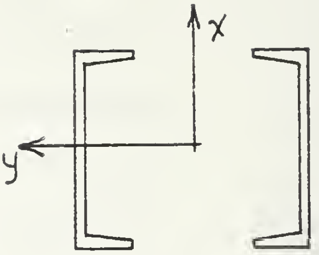
C.3. Substructure Case III Model

The case III model is similar to the case II model except the foundation structure has been changed to AISC W 27x144 I-beams [Ref. 11] and the supported weights have been reduced to 5,000 lb apiece. This model represents an intermediate weight equipment installation such as a main feed pump.

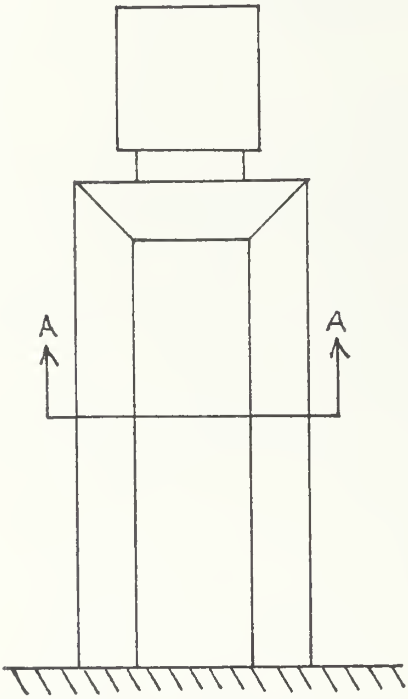
AISC C 10X30 Steel Foundation Properties

$I_{xx} = 333.1$ in.^{4}
$I_{yy} = 206.0$ in.^{4}
$J = 540.0$ in.^{4}

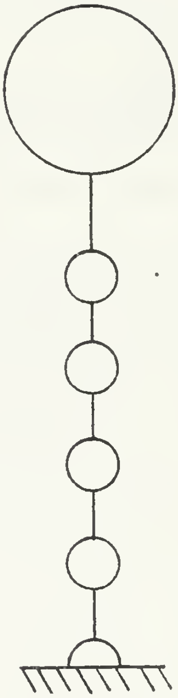
web thickness = 0.673 in.
flange thickness = 0.436 in.
area of channel = 8.82 in.^{2}



Section A-A



REAL WORLD FOUNDATION
AND MASS



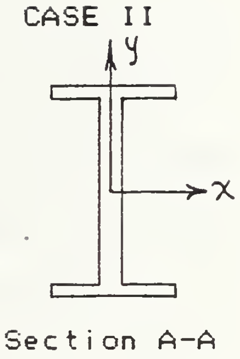
FINITE ELEMENT MODEL
FOR DDAM & ELSHOK

Figure 5 - Case I Equipment and Finite Element Model

AISC W 27X177 Steel Foundation Properties

I_{xx} = 6740 in.^{4}
I_{yy} = 556 in.^{4}
J = 20.1 in.^{4}

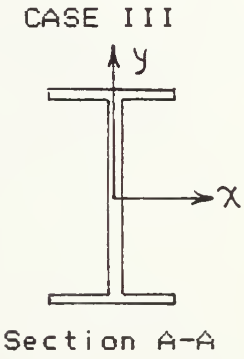
web thickness = 0.725 in.
flange thickness = 1.190 in.
area of beam = 52.2 in.^{2}



AISC W 27X114 Steel Foundation Properties

I_{xx} = 4090 in.^{4}
I_{yy} = 159 in.^{4}
J = 7.36 in.^{4}

web thickness = 0.570 in.
flange thickness = 0.932 in.
area of beam = 33.6 in.^{2}



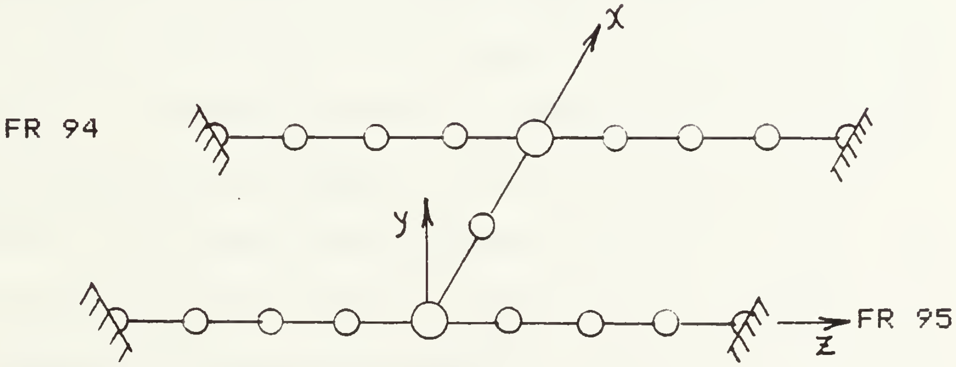


Figure 6 - Case II & III Finite Element Model

V. ANALYSIS

The goal of the analysis procedure used in this investigation is two-fold. The primary objective is to analyze equivalent substructures using DDAM and ELSHOK so a comparison of the maximum predicted deflections can be made. Secondly, any hull/substructure interaction effects are to be noted. The analysis is complicated by several factors. All the calculations are based on constant energy flux which is dependent on charge weight and standoff. Since DDAM shock inputs ultimately represent the results of explosive shock tests, the geometry of the "analytical charge" is invisible to the user and assumed in the empirical shock spectrum. ELSHOK uses inputs of charge weight and standoff to calculate shock loading by eq. (4) so the effects of their variation will change the transient response of the substructure even though the shock intensity is constant. In this analysis, three sets of charge weight and standoff were used. A further complication results due to the fact that DDAM only can be used to calculate maximum relative deflections or forces. ELSHOK calculates transient velocities incurred by the model which must be converted to maximum relative deflections.

A. CASE ANALYSIS PROCEDURE

Each case analysis was begun by first constructing the equipment models to be investigated using SAPIV. A dynamic analysis was performed to find the natural frequencies and mode shapes of the model. This information was saved along with the mass matrix for subsequent DDAM calculations. Using PICRUST, the SAPIV data was then reduced to a suitable form to be merged with the hull structure/fluid data from Phase I calculations. Finally, all the resulting data were integrated using the USLOB code to compute the transient velocity profiles for each equipment installation configuration and charge weight/standoff set.

The PICRUST code was used to specify the installation configuration of each model. Model coordinate system orientation to the hull system is determined by the angle α_0 in fig. (4). The location of the equipment along the longitudinal axis is also specified. For example, in the case I model, the angle is 270 degrees and the base attachment is at frame 95 in the submarine model (within the compartment model). For the case II and III models, two different orientations were investigated, one with the model mounted athwartship and the other with the model mounted vertically, i.e., shock input from the side and bottom of the submarine.

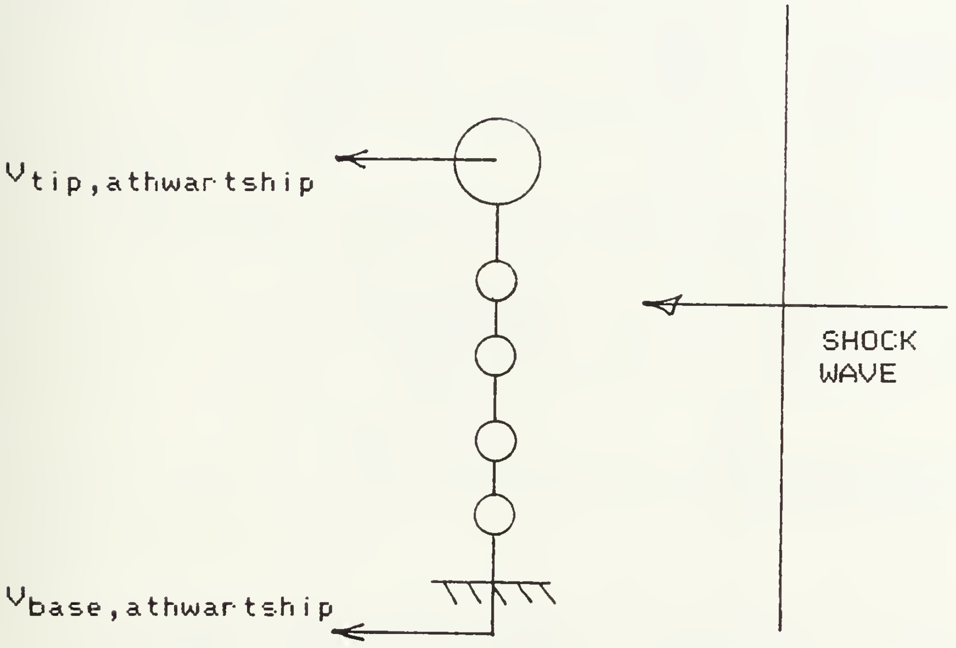
The USLOB code allows input of charge weight and standoff. To investigate how these parameters affect the transient response of the substructure, three sets of values were used for these parameters based on three different charge weights. The parameters chosen are listed in the following table.

Charge Weight (lbs TNT)	Standoff Distance (Inches/Feet)
5,000	1,414/117.9
10,000	2,000/166.7
15,000	2,450/204.2

TABLE III - Charge Weights and Standoffs for Analysis

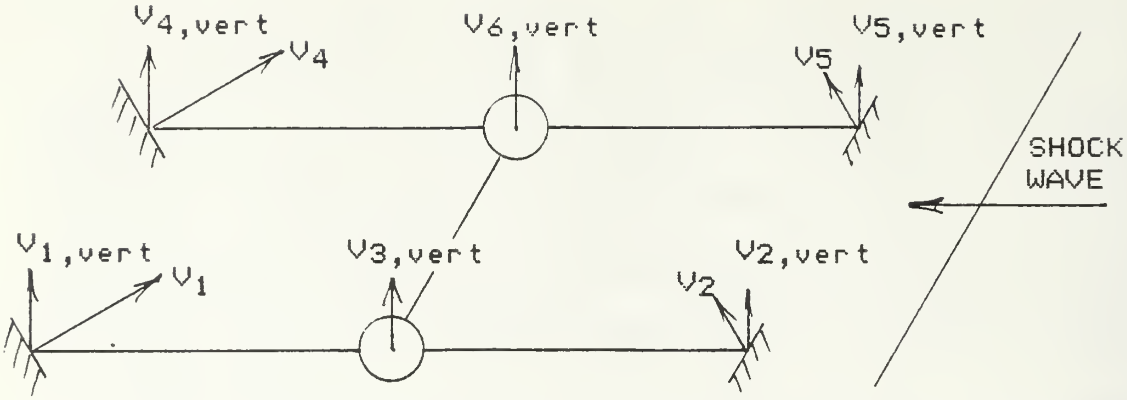
After selection of all factors affecting the geometry of the problem, the time step increment and integration limits were specified. In each case, enough time steps were chosen to capture the peak response amplitudes. This number was found by trial and error.

After calculation of the velocity profiles for a given model, this information was integrated using Simpson's 1/3 rule to obtain a deflection history and the maximum deflection response of the model. As alluded to earlier, the models were constructed so that suitable differences taken between the velocity profiles of designated points would yield the relative deflection, at any instant in time, of the point in question. This procedure unfortunately relies, to a certain extent, on symmetry in the model. For instance, in the case I model, the deflection of the weight on the end of the cantilever in the athwartship direction can be obtained by integrating the difference between the velocity histories of the base and the tip of the beam. Figures (7) and (8) show schematically the differences taken to calculate deflections for each model configuration.

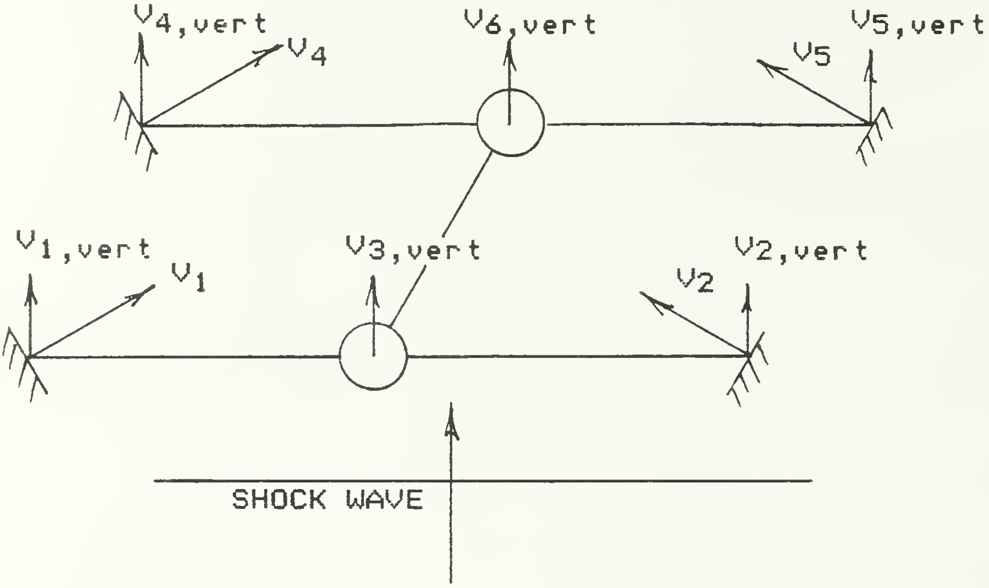


$$V_{rel} = V_{base,athwartship} - V_{tip,athwartship}$$

Figure 7 - Relative Velocities Used to Calculate Relative Deflection Between Mass and Base for Case I



Vertical Relative Velocity of Nodes 3 & 6 wrt fixed base Nodes (shock wave from ATHWARTSHIP)



Vertical Relative Velocity of Nodes 3 & 6 wrt fixed base Nodes (shock wave from below keel)

$$V_{3,rel} = V_{3,vert} - (V_{1,vert} + V_{2,vert})/2$$
$$V_{6,rel} = V_{6,vert} - (V_{4,vert} + V_{5,vert})/2$$

Figure 8 - Case II & III Relative Velocity Calculations for Athwartship and Vertical Shock Waves

After the ELSHOK results were obtained for each model, DDAM was used to calculate the maximum deflections using the information saved from the SAPIV runs. A file was constructed, using an editing program, to input the masses, natural frequencies, and mode shapes for the model to the DDAM program. During execution, the program utilizes prompts to query the user about the type of installation and shock input direction. The maximum relative deflection is calculated by the NRL formula [Ref. 12]:

$$\Delta_m = \mathrm{abs}(\Delta_{i,max}) + \sqrt{\Sigma(\Delta_i)^2 - \Delta_{i,max}^2} \qquad (5)$$

where;

$\mathrm{abs}(\Delta_{i,max})$ = the largest modal deflection of a point on the model

Δ_i = modal relative deflection at a point on the model

Δ_m = maximum relative deflection of a point on the model

This formula is used to reflect the fact that all modes do not experience their maximum delections simultaneously.

Figures (9), (10), and (11) summarize the model configurations and shock input directions for cases I, II, and III. Tables IV, V, and VI are summaries of the information used in the DDAM and ELSHOK calculations of these cases. A full case I analysis is presented in Appendix C.

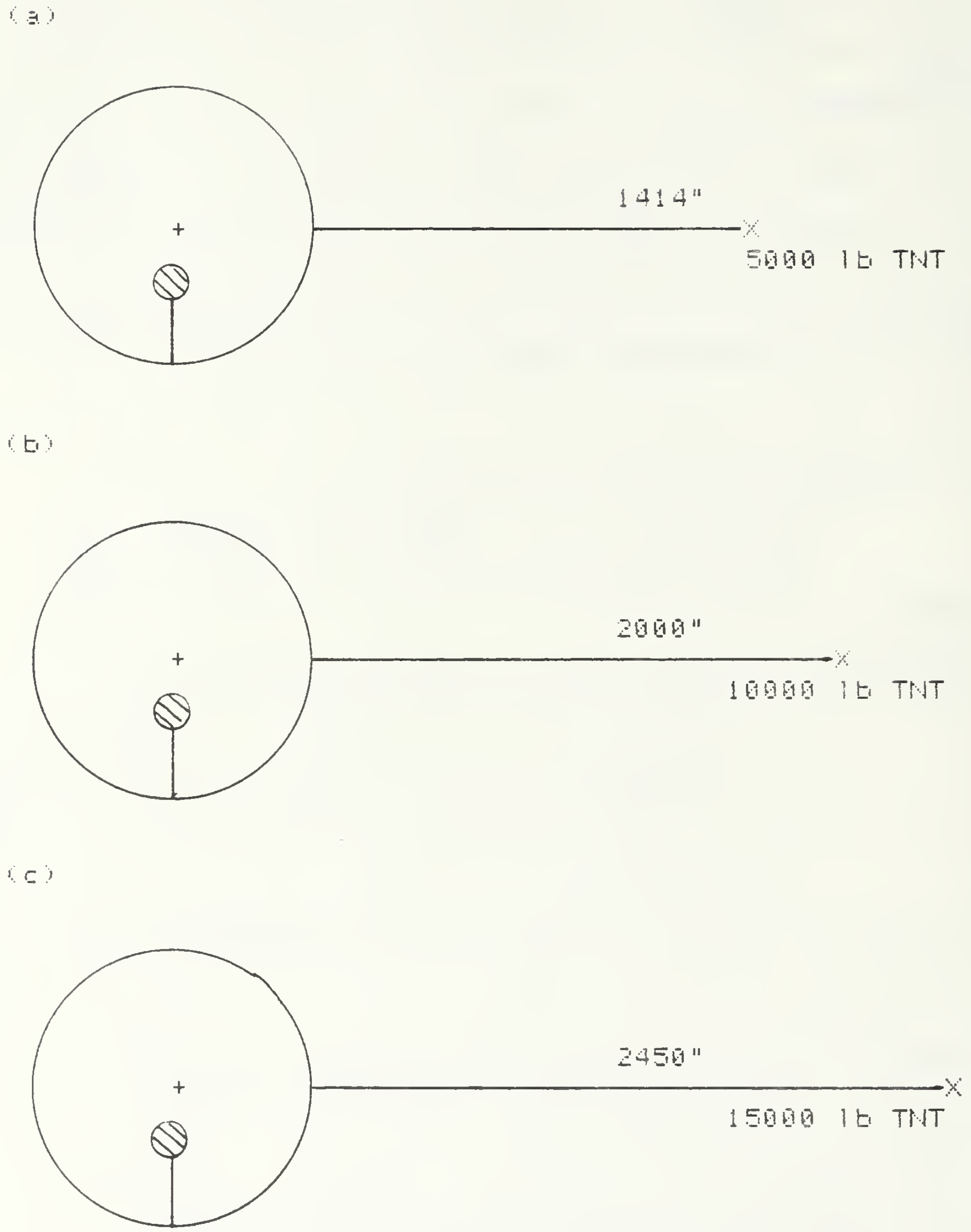


Figure 9 - Shock configurations for Case I

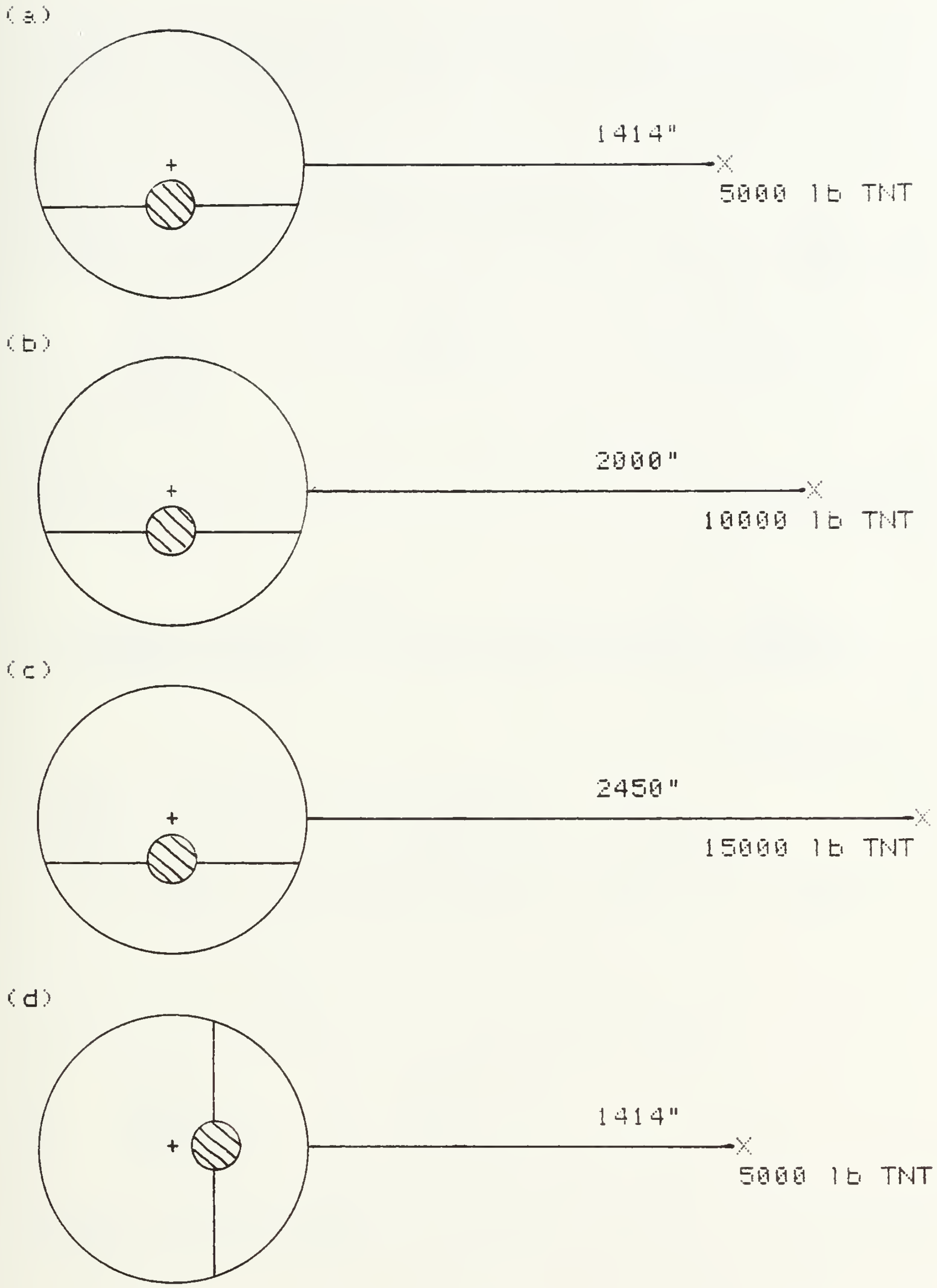


Figure 10 - Shock configurations for Case II

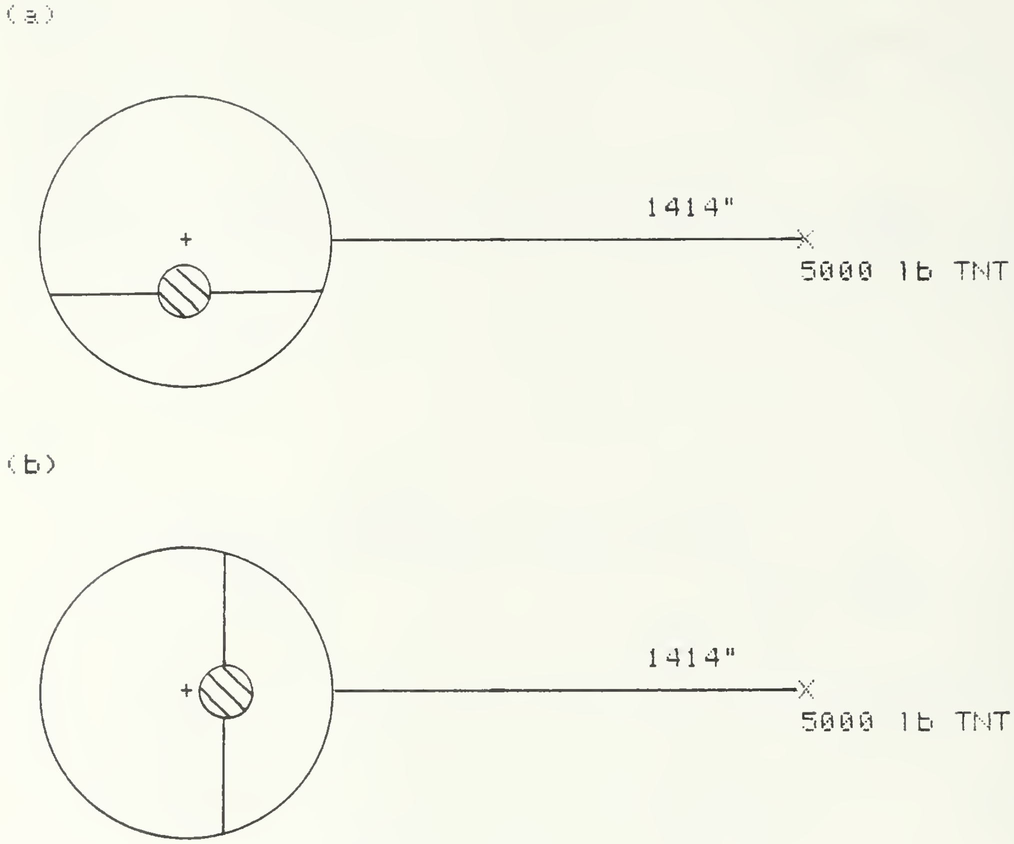


Figure 11 - Shock configurations for Case III

TABLE IV - Case I Inputs to DDAM and ELSHOK

Number of Degrees of Freedom	18
Number of Connected Degrees of Freedom	3
Number of Unconnected Degrees of Freedom	15
Number of Interface Points	1
Number of Frequencies In Analysis	10

Substructure Natural Frequencies (cps)

1	445.41	5	7608.71	8	12169.6
2	1054.85	6	9558.05	9	12284.0
3	1343.07	7	10454.9	10	18014.2
4	4037.05				

Number of Time Steps In the Analysis	1201
Size of Time Steps	0.5E-6 sec.

TABLE V - Case II Inputs to DDAM and ELSHOK

Number of Degrees of Freedom	34
Number of Connected Degrees of Freedom	4
Number of Unconnected Degrees of Freedom	30
Number of Interface Points	4
Number of Frequencies In Analysis	5

Substructure Natural Frequencies (cps)

1	48.7743	4	551.148
2	392.390	5	583.723
3	392.508		

Number of Time Steps In the Analysis	1201
Size of Time Steps	1.0E-5 sec.

TABLE VI - Case III Inputs to DDAM and ELSHOK

Number of Degrees of Freedom	34
Number of Connected Degrees of Freedom	4
Number of Unconnected Degrees of Freedom	30
Number of Interface Points	4
Number of Frequencies In Analysis	10

Substructure Natural Frequencies (cps)

1	52.7625	5	570.582	8	1213.51
2	380.0991	6	853.971	9	1483.73
3	381.061	7	1213.45	10	1492.67
4	537.903				

Number of Time Steps In the Analysis	1801
Size of Time Steps	2.0E-5 sec.

VI. RESULTS

Although the number of cases and their permutations explored in this investigation are not numerous, they have been contrived to accentuate the similarities and differences between the DDAM and ELSHOK methods of analysis. As mentioned previously, ELSHOK provides a great deal more information about the shock response of submarine-installed equipment than DDAM. However, DDAM is not intended to be a theoretical tool but rather is simply a design check. For this reason, where ELSHOK will predict different maximum deflections depending on charge weight and standoff, DDAM will predict only one value for all variations.

A. CASE I (1,000 LB CASE)

The predicted responses of DDAM and ELSHOK compare well for this case. The DDAM calculation yields a maximum deflection of 0.0143" for the end of the cantilever beam when subjected to an athwartship shock input, whereas the ELSHOK calculation predicted a 0.0131" deflection for a 10,000 lb charge and a 2,000 inch standoff as in fig (9b). The 15,000 lb and 5,000 lb charges both caused slightly lower deflections. In this case, DDAM is more conservative (about 9%) than the ELSHOK calculation. This illustrates that where the equipment weight is only about 1,000 lb, little interaction is to be expected between the hull response which is relatively low frequency, and the higher frequency equipment response. The highest hull frequency is only about 100 Hz. Coupling effects between the responses of the equipment mass and the hull mass are insignifigant due to the large ratio of the masses. If the mass of only segment five in the full model is considered to be the entire hull mass, then the effective mass of the hull is about 4100 slugs. The mass of the model is less than 2.9 slugs. This yields a mass ratio of about 0.00073. DDAM is based upon the approximation that the hull mass can be considered infinite which implies a mass ratio of 0.00000... providing no account for coupling other than through the safety factor built into its design spectrum. The close agreement between ELSHOK and DDAM is probably due to the lack of response coupling in both methods of analysis.

B. CASE II (20,000 LB CASE)

Two equipment configurations were investigated in the ELSHOK analyses for this case. In the problem geometry in which the submarine is side loaded, figure (9c), the maximum deflection is again in good agreement with that predicted by DDAM; 0.2433 inches in the former versus 0.2744 in the latter. However, the input motion to the structure is not primarily in the direction of maximum deflection in this instance. In the second configuration of this case, corresponding to figure (9d), a much greater deflection (133% greater) is predicted by ELSHOK. There are two possible explanations. Some hull/structure interaction is to be expected because the fundamental natural frequency of the substructure is 48.8 Hz which falls in the middle of the entire range of hull frequencies. If, as in the former case, a hull effective mass of 4100 slugs is assumed, and the model mass is 67.4 slugs in this case, then the ratio of the masses is increased to 0.0164 or about 1.6 percent. In this example, the influence of coupling on the response can be expected to amplify the expected result for an infinite mass hull system considerably. Also a source of uncertainty is the test data upon which the shock input spectrum used in DDAM is based. Most explosive tests are set up with the charge geometry of figure (9c) to avoid problems associated with bubble migration to the hull due to bouyancy effects. In the second configuration, figure (9d), the charge was situated as if it had detonated beneath the keel of the submarine, a realistic possibility when considering modern weapons tactics but perhaps not simulated well by explosive testing. This particular configuration subjects the structure to greater shock input motions in its more flexible direction producing the larger deflections, however DDAM provides the same inputs for both problems.

C. CASE III (10,000 LB CASE)

Two equipment configurations were investigated in the ELSHOK analysis for this case. The results are very similar to the results for case II. In the configuration of Fig. 10(a), a maximum deflection of 0.2184 inch was predicted and in the configuration of Fig 10(b), a maximum deflection of 0.692 inch was predicted by ELSHOK whereas DDAM predicted a maximum of 0.2743 inch for both configurations. Again, the same possible causes can be cited for the large (150%) difference in the second instance. In this case the fundamental frequency of the foundation is 52.7 Hz. The mass of the equipment model in this case is 36.0 slugs yielding a mass ratio between the hull and substructure of about 0.00877.

A summary of the calculated results is presented in Table VII. With the limited calculations available in this work, no attempt could be made to deduce systematically the exact cause for discrepancies between ELSHOK and DDAM in cases II and III.

TABLE VII SUMMARY OF RESULTS

CASE NUMBER	EQUIP. WEIGHT	CHARGE WEIGHT	STANDOFF	MAXIMUM DEFLECTIONS (in.)	
				DDAM	ELSHOK
UNITS	(lbs)	(lbs TNT)	(in.)	(in.)	(in.)
Ia	1000	5000	1414	0.0143	0.0119
Ib	1000	10000	2000	0.0143	0.0131
Ic	1000	15000	2450	0.0143	0.0125
IIa	10000	5000	1414	0.2744	0.1888
IIb	10000	10000	2000	0.2744	0.2138
IIc	10000	15000	2450	0.2744	0.2433
IId	10000	5000	1414	0.2744	0.6390
IIIa	20000	5000	1414	0.2763	0.2184
IIIb	20000	5000	1414	0.2763	0.6920

VII CONCLUSIONS

Since its adoption by the naval shock community, DDAM has provided an easy-to-use and convenient means to design check equipment installations proposed for submarines. It is independent of any well defined submarine structural input and can be applied early in the overall design process before such details are well developed. However, the same qualities that allow for the flexibility in DDAM may also contribute to possible inaccuracies when this method is applied to submarines of radically different size or design than the ones reflected in the empirical Design Spectrum.

The work in this thesis is in no way construed to be an all-encompassing evaluation of DDAM and ELSHOK. From the infinite number of possible equipment configurations and sizes, three simple models have been selected which examine only the hull mounted equipment problem. The intent of this investigation has been to examine the capability of the two methods to predict the shock response of these equipments and not to rank one against the other. ELSHOK or any variation of this code is much too complex and computer resource intensive to use as a design tool and was not intended for this purpose.

In the case of equipment whose response is relatively high frequency compared to the hull response, DDAM and ELSHOK deflection predictions are in good agreement. The maximum hull response frequency is limited to about 100 Hz for the 6900 LT submarine used in this work. The good correlation is attributed to the lack of interaction and coupling effects between the hull and substructure. When the response frequencies of the substructure approached those of the hull and the mass of the substructure became a significant portion of the overall system, the comparisons between ELSHOK and DDAM deflection predictions were not good.

The indications of this work are that DDAM does not correctly reflect the hull-substructure response coupling amplification which becomes apparent when the substructure response is tuned to the hull response. Additionally, the empirical database upon which DDAM is reliant for shock input may fail to represent the heavy equipment problem well.

More basic research remains to be done before many of the questions or criticisms posed by this thesis can be considered conclusive. Due to the scarcity of published reports describing the input data used to generate the design shock values used by DDAM, the application of this method as a general design qualification should be regarded with caution. The basis of the Design Spectrum used in DDAM should be available for analysis and revision.

Additional work remains to be done to determine where the discrepancies between ELSKOK and DDAM first become significant. The cases analyzed here represent both ends of the substructure response spectrum but lend little information to what happens in the transition region between the low-interaction and high-interaction frequency response regimes.

DDAM should be retained as a design check method. However, some modifications are recommended here. The present Design Shock inputs used in DDAM should be updated to reflect the incresed size of modern day submarines. If the details of the original formulation were known or revealed, the current values could be updated by generating new analytical data based on computer simulations. This new spectrum could then be verified by explosive testing. It is apparent from the hull-substructure coupling phenomenon noted here that a modified shock spectrum should be formulated for each new class of submarine which would reflect the peculiarities of this class versus the previous ones.

At the present time, when new submarines cost billions of dollars and are by no means numerous, every effort must be made to ensure their survival in an underwater explosive shock environment. This should include taking a new look at DDAM and ensuring it upholds the standards set by naval shock policy. There is a great deal of flexibility inherent in DDAM and together with modern numerical techniques it can be updated to reflect current technology.

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APPENDIX A : DDAM USER'S MANUAL AND PROGRAM LISTING

The DDAM Program contained herein provides an easy means to perform a small to medium-scale DDAM analysis of a given internal equipment design. The program is written in IBM PC BASIC language and is not restricted to submarine analyses only but includes the standard DDAM case possibilities. The solution algorithm follows the method cited in Ref. 2.

A. USING THE DDAM PROGRAM

A.1. Option Selections

The DDAM program is menu-driven and written to be self-explanatory. Prior to starting the program, it must be available on a diskette along with the BASICA.COM program.

To start the program type:

```
BASICA<ENTER>
<F3>DDAM<ENTER>
<F2>
```

The first command line loads and executes the BASIC interpreter and the second line loads the DDAM program. The third line starts execution of the DDAM Program.

Upon starting, the title of the program (DDAM) is written on the screen and several seconds later a message appears describing the provided functions. Follow the directions.

Four execution options will appear for source of data and program exit to the operating system. They are:

[1] Input Mode Shapes and Mass Matrix for the problem from Keyboard

[2] Input Mode Shapes and Mass Matrix from a disk file

[3] Input a Mass Matrix and Stiffness Matrix for previously formulated equations of motion

[5] Exit to DOS

No option [4] is present; however, provisions have been made to install a user-defined subroutine at line 25000 in the program.

Option [1] is useful for small problems and is not recommended for situations involving more than four degrees of freedom. It allows all data input to be carried out using the keyboard. In larger problems, the entry of mode shapes becomes tedious and error prone.

Option [2] is recommended for most problems. It allows the use of a diskfile for input. The file is user-specified and utilizes a free-format data structure. The information must be present in the file in a set order which is described later.

Selection of option [3] causes a message to be displayed stating that the JACOBI program must first be run to solve the eigenvalue problem for mode shapes and natural frequencies. This program listing follows the DDAM listing in this appendix. Incorporating the JACOBI program in DDAM would have reduced significantly the size of problem which could be handled. The JACOBI program is included as a convenience to the reader and was not integral to the analysis of the case studies done in this thesis. Its operation is described later.

A.2. Option[1] Execution

Selecting option [1] allows input of the masses, modes, and natural frequencies of the problem from the keyboard. The number of modes and masses are first input. A mass input subroutine queries the user interactively for the diagonal entries of the mass matrix. After input is completed, the diagonal elements are displayed enabling the user to make corrections as necessary. A zero correction terminates mass matrix input. Next, the program asks for input of the natural frequencies of the system. It requires one natural frequency for each mode shape. The input format is similar to the one used to input the mass elements. The natural frequencies are required in units of radians/second. Each mode shape is then input. After initializing each mode, a correction option is provided.

The program next calculates the participation factors and modal weights for the problem.

Following these preliminary steps, DDAM requires information to fix the installation details for the equipment and type of analysis to be carried out. The standard cases of Ref. 2 are allowed. Once the case is fixed, the Design Values are calculated and displayed as DA(1)...DA(n) where n is the number of modes selected for the analysis. The Design Values are the equivalent static accelerations calculated from empirical formulas for each mode.

Several output options are provided. Modal forces or deflections or both can be selected. After selection, the appropriate calculations are made and the results displayed. Initially a print option was separately provided. However, in the present version, selection of the display to screen option with printer on will cause output to go to the screen and the printing device. Disabling the printer will cause output to go only to the screen. Following the output options, choices are provided to change the equipment installation type and repeat the analysis or to exit the program.

A.3. Option [2] Execution

Selecting option [2] allows input of masses, natural frequencies, and mode shapes from a disk file. After the data is read in, the program execution is similar to that in option [1]. Option [2] prompts the user for the dimension of the mass matrix, the number of modes in the analysis, and the name of the input file. The input file is a free-format ASCII file containing the masses, natural frequencies, and mode shapes for the problem. This file may be constructed from structural analyzer (SAPIV) output or any other problem formulation method using a suitable editor program. (EDLIN, the editor provided with the "IBM Disk Operating System" is not recommended for this purpose due to its line orientation.) The format for the input file follows:

```
 mass(1) .... mass(m)       (slugs)
omega(1) .... omega(m)      (rad/s)
phi(1,1) .... phi(1,n)
phi(m,1) .... phi(m,n)

where     m = number of masses and
          n = number of modes in the analysis
```

In the above format, the data is read in sequentially from left to right. The data is echoed to the screen and/or printer in order to provide a check for proper input operation.

B. PROGRAM LISTING - D D A M

```
10 CLS: KEY OFF : LOCATE 8,1,0
20 PRINT"**********************************************************************
****"
21 PRINT"**
  **"
30 PRINT"**           DDDD       DDDD        AAA        MMM   MMM
  **"
40 PRINT"**           DD   D     DD   D      A    A      MM  M  MM
  **"
50 PRINT"**           DD   D     DD   D     AAAAAAA      MM  M  MM
  **"
60 PRINT"**           DD   D     DD   D     A      A     MM     MM
  **"
70 PRINT"**           DDDD       DDDD       A      A     MM     MM
  **"
80 PRINT"**
  **"
90 PRINT"**          DYNAMIC     DESIGN     ANALYSIS        METHOD
  **"
100 PRINT"**
  **"
110 PRINT"**
  **"
120 PRINT"**********************************************************************
****"
121  DIM MASS(40)
122  DIM PHI(40,40)
123  DIM W(40)
124 DIM MX(40,40),MX2(40,40),SUM1(40),SUM2(40),P(40)
125 DIM WA(40)
127 DIM V0(40),A0(40),DA(40)
128 DIM AA(40),VA(40),F(40,40),DEFL(40),DELTA(40,40)
130 FOR I = 1 TO 5000 : NEXT I
140 CLS: LOCATE 1,1,0
150 PRINT"   The purpose of this program is to allow the user a convenient meth
od":PRINT
160 PRINT"by which to carry out a small to medium sized DDAM analysis of a give
n":PRINT
170 PRINT"piece of equipment.  Familiarity with NORMAL MODE ANALYSIS and some u
n-":PRINT
180 PRINT"derstanding of the theory behind DDAM is prerequisite to confident us
e":PRINT
190 PRINT"of this program.  The program is prompt driven but the user should hav
e ":PRINT
200 PRINT"available to him / her either :":PRINT:PRINT
210 PRINT"                A.)   Mode Shapes and a Mass Matrix for the"
220 PRINT"                      problem of interest.":PRINT:PRINT
230 PRINT"                B.)   A Mass Matrix and Stiffness Matrix from"
```

```
240 PRINT"                         previously formulated EQUATIONS of MOTION":PRINT
:PRINT:PRINT
250 PRINT"                 ( Press ANY key to continue )":LOCATE 25,1,0
260 A$ = INKEY$: IF A$ = "" THEN 260
270 CLS:
280 LOCATE 5,1,0
290 PRINT"   In order to initialize the program input, choose one of the follow
ing":PRINT
300 PRINT"menu selections ======)":PRINT:PRINT
310 LOCATE 10,20,0 :PRINT"[1]  Input Mode Shapes and Mass Matrix"
320 LOCATE 11,20,0 :PRINT"     for the problem from keyboard"
325 LOCATE 13,20,0 :PRINT"[2]  Input Mode Shapes and Mass Matrix"
326 LOCATE 14,20,0 :PRINT"     from a disk file "
330 LOCATE 16,20,0 :PRINT"[3]  Input a Mass Matrix and Stiffness Matrix"
340 LOCATE 17,20,0 :PRINT"     for previously formulated equations of"
350 LOCATE 18,20,0 :PRINT"     motion"
360 LOCATE 20,20,0 :PRINT"[5]  Exit to DOS"
370 A$ = INKEY$ : IF A$ >= CHR$(49) AND A$ <= CHR$(53) GOTO 400
380 IF A$ = "" GOTO 370
390 BEEP : GOTO 370
400 B = VAL(A$) : CLS
410 ON B GOSUB 5000,15000,20000,25000,500
500 SYSTEM :END
600 '***********************************************************************
601 '     S U B R O U T I N E  T O  I N P U T  M A S S  M A T R I X
603 '***********************************************************************
605  INPUT "Enter the dimension of the Mass Matrix ==>  "; N
610  IF N <= 20 GOTO 622
620  PRINT:PRINT:PRINT"*****  PROBLEM SIZE IS LIMITED TO 20 X 20 MATRICES  ****
* ":PRINT:PRINT: GOTO 600
621  PRINT:PRINT:PRINT
622  INPUT "Enter the number of modes you wish to use ==> ";M
630  CLS: PRINT"***** Enter the elements of the DIAGONAL Mass Matrix *****":PRI
NT:PRINT
640  PRINT"      If you make an error you will have an opportun-"
650  PRINT"                    ity later to correct it.":PRINT:PRINT
670  FOR I = 1 TO N
680  PRINT "   M(";I;",";I;") == ";:INPUT" ", MASS(I)
690  IF (I = 5) OR (I = 10) OR (I = 15) THEN CLS
700  IF MASS(I) <> 0 GOTO 730
710  PRINT" ***** MASS MATRIX MUST BE POSITIVE DEFINITE --- INPUT NON-ZERO VALU
E ****"
720  PRINT: GOTO 680
730  PRINT: NEXT I
740 CLS
750 FOR I = 1 TO N
760     PRINT "M(";I;",";I;") = ";MASS(I),
770 NEXT I
780 PRINT:PRINT:PRINT
790 PRINT"Enter diagonal element number to correct mistaken entries or "
800 PRINT:INPUT "           Enter ( ZERO ) to continue =>", RESPONSE
```

```
810 IF RESPONSE = 0 THEN RETURN
820 IF RESPONSE <= 0 OR RESPONSE > N  THEN CLS : GOTO 750 ELSE I = RESPONSE
850 PRINT:PRINT:INPUT "Enter correct element value => ", M(I)
860 PRINT:PRINT"M(";I;",";I;") CHANGED TO ";MASS(I)
870 FOR I = 1 TO 1500 : NEXT I : CLS : GOTO 750
880 RETURN
1000 '************************************************************************
1010 '          S U B R O U T I N E  T O  I N P U T  M O D E  S H A P E S
1020 '************************************************************************
1050 CLS: LOCATE 5,1,0
1060 PRINT"***** Enter OMEGA's corresponding to Mode Shapes *****":PRINT
1070 PRINT"                   ( smallest to largest )":PRINT:PRINT
1080 FOR I = 1 TO M
1090 PRINT "    omega(";I;") =   ";:INPUT" ",W(I)
1100 IF (I=5) OR (I=10) OR (I=15) THEN CLS
1110 NEXT I
1120 CLS : FOR I = 1 TO M
1130    PRINT"OMEGA(";I;") = ";W(I),
1140 NEXT I
1150 PRINT:PRINT:PRINT
1160 PRINT "Enter frequency number to correct mistaken entries or ":PRINT
1170 INPUT "                         Enter < ZERO > to continue ==>",RESPONSE
1180 IF RESPONSE = 0 THEN GOTO 1230
1190 IF RESPONSE <= 0 OR RESPONSE > N  THEN CLS : GOTO 1120 ELSE I = RESPONSE
1200 PRINT:PRINT:INPUT "Enter correct frequency value => ", W(I)
1210 PRINT:PRINT"OMEGA(";I;")  changed to ";W(I)
1220 FOR I = 1 TO 2000 : NEXT I : GOTO 1120
1230 CLS: LOCATE 5,1,0
1240 PRINT"***** Enter EIGENVECTOR's corresponding to Mode Shapes *****":PRINT
1250 PRINT"                       ( begin with Mode One )":PRINT:PRINT
1260 FOR I = 1 TO M
1270    FOR J = 1 TO N
1280            PRINT"   MODE SHAPE ";I;"   Phi(";J;") =  ";:INPUT" ",PHI(I,J)
1290            IF (J=5) OR (J=10) OR (J=15) THEN CLS : LOCATE 5,1,0
1300    NEXT J
1305    CLS : PRINT:PRINT
1310    PRINT "*************** M O D E   N U M B E R   ";I;"  ***************"
1320    PRINT:PRINT:FOR J = 1 TO N
1330            PRINT" Phi(";J;") = ";PHI(I,J),
1340    NEXT J
1350    PRINT:PRINT
1360    PRINT"Enter element number in mode to change or":PRINT
1370    INPUT"        Enter < ZERO > to continue ==> ", RESPONSE
1380    IF RESPONSE = 0 THEN GOTO 1430
1390    IF RESPONSE <= 0 OR RESPONSE > N THEN CLS:GOTO 1310 ELSE J = RESPONSE
1400    PRINT: INPUT"Enter correct element value =>";PHI(I,J):PRINT
1410    PRINT"Phi(";J;")  CHANGED TO ";PHI(I,J)
1420    FOR K = 1 TO 2000 : NEXT K : CLS : GOTO 1310
1430 CLS:NEXT I
1440 RETURN
5000 '************************************************************************
```

```
5005 '  S U B R O U T I N E  T O  D R I V E  M O D E / M A S S  I N P U T
5010 '************************************************************************
5020 LOCATE 5,1,0
5030 PRINT"  The program has been initialized to allow user input of the":PRINT
5040 PRINT"Mode Shapes and Mass Matrix.  If you desire one of the other op-":PR
INT
5050 PRINT"tions, PRESS < escape key >; ......otherwise ==>":PRINT:PRINT
5055 PRINT"        PRESS < space bar > to continue >"
5060 A$ = INKEY$ : IF A$ = CHR$(27) GOTO 270
5070 IF A$ <> CHR$(32) GOTO 5060
5075 CLS : LOCATE 5,1,0 : GOSUB 600
5080 CLS : LOCATE 5,1,0 : GOSUB 1000
5090 CLS : GOSUB 6000
5100 CLS: LOCATE 25,1,0
5110 PRINT
5120 GOSUB 8000
5130 CLS: GOSUB 8200
5140 CLS : GOSUB 10000
6000 '***********************************************************************
6010 '    S U B R O U T I N E  T O  F I N D  P A R T I C I P A T I O N
6020 '                          F A C T O R S
6030 '***********************************************************************
6040 LOCATE 25,1,0
6050 T$(1) = TIME$
6060 PRINT"    CALCULATING PARTICIPATION FACTORS == start : ";TIME$
6080 FOR I = 1 TO M
6090    FOR J = 1 TO N
7000            MX(I,J) = MASS(J) * PHI(I,J)
7010            MX2(I,J) = MX(I,J) * PHI(I,J)
7020    NEXT J
7030 NEXT I
7040 FOR I = 1 TO M
7050    SUM1(I) = MX(I,1)
7060    SUM2(I) = MX2(I,1)
7070    FOR J = 2 TO N
7080            SUM1(I) = SUM1(I) + MX(I,J)
7090            SUM2(I) = SUM2(I) + MX2(I,J)
7100    NEXT J
7110 NEXT I
7120 FOR I = 1 TO M
7130    P(I) = SUM1(I) / SUM2(I)
7140 NEXT I
7150 FOR I = 1 TO M
7160    MBAR(I) = P(I) * SUM1(I)
7170 NEXT I
7180 LOCATE 25,60,0 : PRINT"  done:  ";TIME$
7190 DUMMY = M
7200 IF DUMMY > 10 THEN K% = M/2 ELSE K% = M
7210 L=1:J=0
7215 LOCATE 5,1,0
7220 PRINT"***** PARTICIPATION FACTORS AND MODAL MASSES *****":PRINT:PRINT
```

```
7221 LPRINT"***** P   F A C T O R S  A N D  M O D A L  M A S S E S *****"
7222 LPRINT
7225 PRINT" N    MODAL PARTICIPATION          MODAL MASS "
7226 PP$ ="##       ##.######^^^^           ##.######^^^^"
7227 LPRINT" N    MODAL PARTICIPATION          MODAL MASS "
7230 FOR I = L TO K%
7240    PRINT USING PP$ ; I,P(I),MBAR(I)
7241    LPRINT USING PP$ ; I,P(I),MBAR(I)
7250    J = J + 1
7260 NEXT I
7270 IF DUMMY > 10 AND J < 11 THEN A$ = INKEY$:GOTO 7280 ELSE GOTO 7311
7280    PRINT:PRINT:PRINT
7281 LPRINT:LPRINT
7290    PRINT"                          PRESS ANY KEY TO CONTINUE..."
7300    IF A$ = "" THEN GOTO 7300
7310    K% = M : L = 10: CLS : GOTO 7215
7311 PRINT:PRINT:PRINT"                         PRESS ANY KEY TO CONTINUE..."
7320 A$ = INKEY$ : IF A$ = "" THEN GOTO 7320
7330 RETURN
8000 '*************************************************************************
8010 '       S U B R O U T I N E  T O  C A L C U L A T E  M O D A L
8020 '                        W E I G H T S
8030 '*************************************************************************
8035 CLS:LOCATE 5,1,0
8040 PRINT"***** C A L C U L A T E D  M O D A L  W E I G H T S *****"
8041 LPRINT"***** C A L C U L A T E D  M O D A L  W E I G H T S *****"
8045 WW$ = "##      ###.######"
8046 PRINT : PRINT " N    WEIGHT IN KIPS"
8047 LPRINT " N    WEIGHT IN KIPS"
8050 PRINT
8051 LPRINT
8070 FOR I = 1 TO M
8080    WA(I) =386 * SUM1(I) * P(I) / 1000
8090    PRINT USING WW$ ; I,WA(I)
8091    LPRINT USING WW$ ; I,WA(I)
8095 NEXT I
8100 LPRINT:LPRINT:PRINT:PRINT:PRINT"                              Press any Ke
y to continue..."
8110 A$ = INKEY$: IF A$ = "" THEN GOTO 8110
8120 RETURN
8200 '*************************************************************************
8210 '     S U B R O U T I N E  T O  D E T E R M I N E  G E O M E T R Y
8220 '         O F  A N A L Y S I S  A N D  A (0)  , V (0)  , D (A)
8230 '*************************************************************************
8240 PRINT"     Some information is now needed to complete the details about th
e"
8250 PRINT"type of vessel the structure I am analyzing is installed in and whet
her"
8260 PRINT"or  not the analysis is to consider elastic or elastic-plastic defor
ma-"
8270 PRINT"tions."
```

```
8280 PRINT:PRINT
8290 PRINT"PLEASE ENTER ONE OF THE FOLLOWING =>"
8300 LOCATE 9,20,0: PRINT"[1]   SUBMARINE     ( hull mounted system )"
8310 LOCATE 11,20,0:PRINT"[2]   SUBMARINE     ( deck mounted system )"
8320 LOCATE 13,20,0:PRINT"[3]   SUBMARINE     ( shell plating mounted system )"
8330 LOCATE 15,20,0:PRINT"[4]   SURFACE SHIP  ( hull mounted system )"
8340 LOCATE 17,20,0:PRINT"[5]   SURFACE SHIP  ( deck mounted system )"
8350 LOCATE 19,20,0:PRINT"[6]   SURFACE SHIP  ( shell plating mounted system )"
8360 A$ = INKEY$: IF A$>=CHR$(49) AND A$ <= CHR$(54) GOTO 8390
8370 IF A$ = "" THEN GOTO 8360
8380 BEEP: GOTO 8360
8390 B = VAL(A$):CLS
8400 PRINT"ENTER =====>         [1]  for ELASTIC ANALYSIS":PRINT:PRINT
8410 PRINT"                     [2]  for ELASTIC - PLASTIC ANALYSIS "
8420 A$ = INKEY$ : IF A$ >= CHR$(49) AND A$ <= CHR$(50) GOTO 8450
8430 IF A$ = "" THEN GOTO 8420
8440 BEEP: GOTO 8420
8450 C = VAL(A$)
8460 IF C=2 AND (8 = 3 OR B = 6) THEN GOTO 8470 ELSE GOTO 8500
8470 PRINT:PRINT:PRINT:PRINT"***** ELASTIC - PLASTIC OPTION NOT AVAILABLE FOR **
***":PRINT
8480 PRINT"*****       SHELL PLATING MOUNTED SYSTEMS        *****"
8481 LOCATE 10,20,0
8482 PRINT" PRESS ANY KEY TO CONTINUE ....
8483 A$ = INKEY$ : IF A$ = "" THEN GOTO 8483
8490 CLS:GOTO 8240
8500 CLS:LOCATE 5,1,0
8510 PRINT"ENTER =====>         [1]  for motion in VERTICAL     direction":PRINT
8520 PRINT"                     [2]  for motion in ATHWARTSHIP  direction":PRINT
8530 PRINT"                     [3]  for motion in FORE AND AFT direction"
8540 A$ = INKEY$: IF A$ >= CHR$(49) AND A$ <= CHR$(51) GOTO 8570
8550 IF A$ = "" THEN GOTO 8540
8560 BEEP: GOTO 8540
8570 D = VAL(A$)
8571 IF B = 1 THEN LPRINT" SUBMARINE     ( hull mounted system )";
8572 IF 8 = 2 THEN LPRINT" SUBMARINE     ( deck mounted system )";
8573 IF 8 = 3 THEN LPRINT" SUBMARINE     ( shell plating mounted system )";
8574 IF B = 4 THEN LPRINT" SURFACE SHIP  ( hull mounted system )";
8575 IF B = 5 THEN LPRINT" SURFACE SHIP  ( deck mounted system )";
8576 IF B = 6 THEN LPRINT" SURFACE SHIP  ( shell plating mounted system )";
8577 IF C = 1 THEN LPRINT" for ELASTIC ANALYSIS"
8578 IF C = 2 THEN LPRINT" for ELASTIC - PLASTIC ANALYSIS"
8579 IF D = 1 THEN LPRINT:LPRINT " for motion in VERTICAL     direction":LPRINT
8580 IF D = 2 THEN LPRINT:LPRINT " for motion in ATHWARTSHIP  direction":LPRINT
8581 IF D = 3 THEN LPRINT:LPRINT " for motion in FORE AND AFT direction":LPRINT
8590 FOR I = 1 TO N
8600    IF 8 <> 1 THEN GOTO 8680
8610            A0(I) = 10.4* ((480+WA(I))/(20+WA(I)))
8620            V0(I) = 20! * ((480+WA(I))/(100+WA(I)))
8630            IF (D=1 OR D=2) AND C=1 THEN MULT1=1:MULT2=1 : GOTO 9110 ELSE
8640            IF (D=3 AND C=1) THEN MULT1=.4:MULT2=.4 : GOTO 9110 ELSE
```

```
8650            IF (D=1 OR D=2) AND C=2 THEN MULT1=1:MULT2=.5 : GOTO 9110 ELSE
8660            MULT1=.4 : MULT2=.2
8670    GOTO 9110
8680    IF B <> 2 THEN GOTO 8780
8690            A0(I) = 5.2 * ((480 + WA(I))/(20 + WA(I)))
8700            V0(I) = 10! * ((480+WA(I))/(100+WA(I)))
8710            IF (D=1 AND C=1) THEN MULT1=1:MULT2=1 : GOTO 9110 ELSE
8720            IF (D=2 AND C=1) THEN MULT1=2:MULT2=2 : GOTO 9110 ELSE
8730            IF (D=3 AND C=1) THEN MULT1=.8:MULT2=.8 : GOTO 9110 ELSE
8740            IF (D=1 AND C=2) THEN MULT1=1:MULT2=.5 : GOTO 9110 ELSE
8750            IF (D=2 AND C=2) THEN MULT1=2:MULT2=1! : GOTO 9110 ELSE
8760            MULT1 = .8 : MULT2 = .4
8770    GOTO 9110
8780    IF B <> 3 THEN GOTO 8850
8790            A0(I) = 52 * ((480+WA(I))/(20+WA(I)))
8800            V0(I) = 100 * ((480+WA(I))/(100+WA(I)))
8810            IF D=1 THEN MULT1=1:MULT2=1 : GOTO 9110 ELSE
8820            IF D=2 THEN MULT1=.2:MULT2=.2 : GOTO 9110 ELSE
8830            MULT1 = .08 : MULT2 = .08
8840    GOTO 9110
8850    IF B <> 4 THEN GOTO 8950
8860            A0(I) = 20 * ((37.5 + WA(I))*(12 + WA(I))/(6 + WA(I)^2))
8870            V0(I) = 60 * ((12 + WA(I))/(6 + WA(I)))
8880            IF (D=1 AND C=1) THEN MULT1=1:MULT2=1 : GOTO 9110 ELSE
8890            IF (D=2 AND C=1) THEN MULT1=.4:MULT2=.4 : GOTO 9110 ELSE
8900            IF (D=3 AND C=1) THEN MULT1=.2:MULT2=.2 : GOTO 9110 ELSE
8910            IF (D=1 AND C=2) THEN MULT1=1:MULT2=.5 : GOTO 9110 ELSE
8920            IF (D=2 AND C=2) THEN MULT1=.4:MULT2=.2 : GOTO 9110 ELSE
8930            MULT1 = .2 : MULT2 = .1
8940    GOTO 9110
8950    IF B <> 5 THEN GOTO 9050
8960            A0(I) = 10 * ((37.5 + WA(I))*(12 + WA(I))/(6 + WA(I)^2))
8970            V0(I) = 30 * ((12 + WA(I))/(6 + WA(I)))
8980            IF (D=1 AND C=1) THEN MULT1=1:MULT2=1 : GOTO 9110 ELSE
8990            IF (D=2 AND C=1) THEN MULT1=.4:MULT2=.4 : GOTO 9110 ELSE
9000            IF (D=3 AND C=1) THEN MULT1=.4:MULT2=.4 : GOTO 9110 ELSE
9010            IF (D=1 AND C=2) THEN MULT1=1:MULT2=.5 : GOTO 9110 ELSE
9020            IF (D=2 AND C=2) THEN MULT1=.4:MULT2=.2 : GOTO 9110 ELSE
9030            MULT1 = .4 : MULT2 = .2
9040    GOTO 9110
9050            A0(I) = 40 * ((37.5 + WA(I))*(12+ WA(I))/(6 + WA(I))^2)
9060            V0(I) = 120 * ((12 + WA(I))/(6 + WA(I)))
9080            IF D=1 THEN MULT1=1:MULT2=1 : GOTO 9110 ELSE
9090            IF D=2 THEN MULT1=.2:MULT2=.2 : GOTO 9110 ELSE
9100            MULT1 = .1 : MULT2 = .1
9110 V0(I) = MULT2 * V0(I) : A0(I) = MULT1 * A0(I) : NEXT I
9120 FOR I = 1 TO M
9130    AA(I) = A0(I) * 386
9140    VA(I) = V0(I) * W(I)
9150    IF ABS(AA(I)) > ABS(VA(I)) THEN DA(I) = VA(I) ELSE DA(I) = AA(I)
9160    IF ABS(DA(I)) < 2316 THEN DA(I) = 2316
```

```
9170 NEXT I
9171 CLS: LOCATE 5,1,0
9172 FOR I = 1 TO M: PRINT "DA(";I;") = ";DA(I),
9173 NEXT I
9174 PRINT:PRINT:PRINT"                     Press any key to continue ..."
9175 A$ = INKEY$:IF A$ = "" THEN GOTO 9175 ELSE CLS : LOCATE 5,1,0
9176 FOR I = 1 TO M : LPRINT : LPRINT "DA(";I;") = ";DA(I): NEXT I : LPRINT
9180  RETURN
10000 '*************************************************************************
10010 '      S U B R O U T I N E   T O   C A L C U L A T E   M O D A L
10020 '            F O R C E.S   O R   D E F L E C T I O N S
10030 '*************************************************************************
10040 LOCATE 5,1,0
10050 PRINT"     Almost done.... Please ENTER the number of the type of informat
ion"
10060 PRINT:PRINT"you desire as output ===>"
10070 LOCATE 10,1,0 :PRINT"                   [1]  MODAL FORCES"
10080 LOCATE 12,1,0 :PRINT"                   [2]  MODAL DEFLECTIONS"
10090 LOCATE 14,1,0 :PRINT"                   [3]  FORCES & DEFLECTIONS"
10095 LOCATE 16,1,0 :PRINT"                   [4]  CHANGE ANALYSIS TYPE"
10096 LOCATE 18,1,0 :PRINT"                   [5] EXIT TO DOS"
10100 A$ = INKEY$: IF A$ >= CHR$(49) AND A$ <= CHR$(53) THEN GOTO 10140
10110 IF A$ = "" THEN GOTO 10100
10130 BEEP : GOTO 10100
10140 FLAG1 = VAL(A$) : CLS
10150 IF FLAG1 = 2 THEN GOTO 10220
10155 IF FLAG1 = 4 THEN GOTO 16160
10156 IF FLAG1 = 5 THEN SYSTEM
10160 REM ****** CALCULATE MODAL FORCES ********
10170 FOR I = 1 TO M
10180   FOR J = 1 TO N
10190           F(I,J) = P(I) * MASS(J) * PHI(I,J) * DA(I)
10200   NEXT J
10210 NEXT I
10220 IF FLAG1 = 1 THEN GOTO 12000
10230 REM ****** CALCULATE MODAL DEFLECTIONS *********
10240  FOR I = 1 TO M
10250   FOR J = 1 TO N
10260           DELTA(I,J) = PHI(I,J) * P(I) * DA(I) / W(I)^2
10290   NEXT J
10300 NEXT I
10310 FOR J = 1 TO N
10320   BIGGEST = 0
10330   FOR I = 1 TO M
10340           IF BIGGEST < ABS(DELTA(I,J)) THEN BIGGEST = ABS(DELTA(I,J)): K=I
10350   NEXT I
10360   S = 0
10370   FOR I = 1 TO M
10380           IF I = K THEN GOTO 10400
10390                   S = S + DELTA(I,J)^2
10400   NEXT I
```

```
10410   DEFL(J) = ABS(DELTA(K,J)) + SQR(S)
10420 NEXT J
12000 REM ********* OUTPUT RESULTS ***********
12010 CLS : LOCATE 5,1,0
12020 PRINT "        ENTER                     [1]  TO ECHO RESULTS TO SCREEN":P
RINT:PRINT
12030 PRINT "                                  [2]  TO ECHO RESULTS TO PRINTER":
PRINT:PRINT
12040 A$ = INKEY$
12050 IF A$ >= CHR$(49) AND A$ <= CHR$(50) THEN GOTO 12070
12060 IF A$ = "" THEN GOTO 12040 ELSE BEEP: GOTO 12040
12070 FLAG2 = VAL(A$)
12080 IF FLAG2 = 2 THEN GOTO 12300
12090 IF FLAG1 = 2 THEN GOTO 12190
12100 FOR I = 1 TO M
12110   CLS : LOCATE 5,1,0 : PRINT" *** M O D A L  F O R C E S  F O R  M O D E
(";I;") [lbs] ***" :PRINT
12111 LPRINT:LPRINT" *** M O D A L  F O R C E S  F O R  M O D E  ( ";I;" ) [lb
s] ***" : LPRINT
12112 LPRINT " N ": LPRINT
12114 PRINT  " N " : PRINT
12115 FF$ = "##    ##.######^^^^"
12120          FOR J = 1 TO N
12130                  PRINT USING FF$ ; J,F(I,J)
12131                  LPRINT USING FF$ ; J,F(I,J)
12140          NEXT J
12150          PRINT:PRINT:PRINT:PRINT
12160          PRINT"                   Press any key to continue ..."
12170          A$ = INKEY$: IF A$ = "" THEN GOTO 12170
12180 NEXT I
12190 IF FLAG1 = 1 THEN GOTO 12280
12200 CLS: LOCATE 5,1,0
12210 PRINT" *** D E F L E C T I O N S  A T  M A S S  A T T A C H M E N T  P O
I N T S ***":PRINT:PRINT
12211 LPRINT : LPRINT"** D E F L E C T I O N S  A T  M A S S  A T T A C H M E
N T  P O I N T S **":LPRINT
12215 DD$ = "##.######  "
12220 FOR I = 1 TO N
12230 PRINT"DELTA (";I;") = ";
12231 LPRINT"    DELTA (";I;") = ";
12232 LPRINT USING DD$ ; DEFL(I) ;
12233 LPRINT"in."
12235 PRINT USING DD$ ; DEFL(I) ;
12236 PRINT "in."
12240 NEXT I
12250 PRINT :PRINT:PRINT
12251 LPRINT:LPRINT
12260 PRINT"                                Press any key to continue ..."
12270 A$ = INKEY$ : IF A$ = "" THEN GOTO 12270
12280 CLS : LOCATE 5,1,0
12290 GOTO 10000
```

```
12300 PRINT " OPTION NOT AVAILABLE YET;====> USE < Prtsc > KEY "
12310 FOR I = 1 TO 3000 : NEXT I GOTO 12000
15000 '**********************************************************************
15010 '  S U B R O U T I N E  T O  I N P U T  M A S S / M O D E S
15020 '                    F R O M  D I S K  F I L E
15030 '**********************************************************************
15040 CLS : LOCATE 5,1,0
15050 PRINT" The program has been initialized to allow user input of the":PRINT
15060 PRINT"Mode Shapes,Frequencies, and Masses via an input file.":PRINT
15070 PRINT : PRINT"If you desire one of the other options,":PRINT:PRINT
15080 PRINT"               PRESS <escape key>; ......otherwise ==>":PRINT : PRINT
15090 PRINT"                                    PRESS <space  bar>  to continue "
15100 A$ = INKEY$ : IF A$ = CHR$(27) GOTO 270
15110 IF A$ <> CHR$(32) GOTO 15100
15120 CLS:LOCATE 5,1,0
15130 INPUT "Enter the dimension of the Mass Matrix ===>  ";N
15140 IF N <= 50 THEN GOTO 15170
15150 PRINT:PRINT:PRINT"***** PROBLEM SIZE IS LIMITED TO 50 DEG OF FREEDOM ****
*"
15160 FOR I = 1 TO 1000 : NEXT I : GOTO 15130
15170 PRINT:PRINT:INPUT"Enter the number of modes you wish to use ===>  ";M
15175 PRINT:PRINT:INPUT"Enter the input file name                    ===>  ",FIN$
15180 CLS
15190 '**********************************************************************
15200 ' INPUT MASS,FREQ, AND PHI
15210 '**********************************************************************
15220 OPEN FIN$ FOR INPUT AS #1
15240 FOR I = 1 TO N
15250   INPUT #1, MASS(I)
15260 NEXT I
15270 FOR I = 1 TO M
15280   INPUT #1, W(I)
15290   W(I) = W(I) * 6.283185
15300 NEXT I
15310 FOR J = 1 TO N
15330   FOR I = 1 TO M
15340          INPUT #1,PHI(I,J)
15350   NEXT I
15360 NEXT J
15370 '**********************************************************************
15380 ' OUTPUT MASS, OMEGA, AND PHI
15390 '**********************************************************************
15400 LOCATE 5,1,0 : PRINT"MASS MATRIX DIAGONAL ELEMENTS " : PRINT
15401 LPRINT"***** M A S S  D I A G O N A L  E L E M E N T S *****"
15402 LPRINT
15405 MM$ = "##   ##.#####^^^^    "
15410 FOR I = 1 TO N
15420   PRINT USING MM$ ; I,MASS(I)
15421   LPRINT USING MM$ ; I,MASS(I)
15430 NEXT I
15431 PRINT:PRINT"                       ....PRESS ANY KEY TO CONTINUE"
```

```
15432 A$ = INKEY$ : IF A$ = "" THEN GOTO 15432
15434 CLS
15440 PRINT:PRINT:PRINT
15450 PRINT"FREQUENCIES USED IN ANALYSIS  (RPS)":PRINT
15451 LPRINT
15452 LPRINT"***** F R E Q U E N C I E S  U S E D  I N  A N A L Y S I S  (RPS)
 *****":LPRINT
15460 FOR I = 1 TO M
15470   PRINT I;"   ";W(I)
15471   LPRINT I;"    ";W(I)
15480 NEXT I
15481 PRINT:PRINT"                        ....PRESS ANY KEY TO CONTINUE"
15482 A$ = INKEY$ : IF A$ = "" THEN GOTO 15482
15484 CLS
15490 PRINT:PRINT:PRINT
15491 LPRINT:LPRINT
15500 PRINT"MODES USED IN ANALYSIS":PRINT
15501 LPRINT"***** M O D E S  U S E D  I N  A N A L Y S I S *****":LPRINT
15510 K = M : U$ = "##.#####^^^^   "
15520 IF K > 5 THEN GOTO 15600
15530   FOR J = 1 TO N
15540           FOR I = 1 TO M
15550                   PRINT USING U$; PHI(I,J);
15551                   LPRINT USING U$; PHI(I,J);
15560           NEXT I
15570           PRINT " "
15571           LPRINT " "
15580   NEXT J
15590   PRINT:PRINT
15591 LPRINT : LPRINT
15592 PRINT: PRINT"                       ....PRESS ANY KEY TO CONTINUE"
15593 A$ = INKEY$ : IF A$ = "" THEN GOTO 15593
15594 CLS: GOTO 15740
15600   FOR J = 1 TO N
15610           FOR I = 1 TO 5
15620                   PRINT USING U$; PHI(I,J);
15621                   LPRINT USING U$; PHI(I,J);
15630           NEXT I
15640           PRINT " "
15641           LPRINT " "
15650   NEXT J
15660   PRINT:PRINT:LPRINT:LPRINT
15661 PRINT"                        ....PRESS ANY KEY TO CONTINUE"
15662 A$ = INKEY$ : IF A$ = "" THEN GOTO 15662
15663 CLS: PRINT: PRINT
15670   FOR J = 1 TO N
15680           FOR I = 6 TO N
15690                   PRINT USING U$; PHI(I,J);
15691                   LPRINT USING U$; PHI(I,J);
15700           NEXT I
15710           PRINT " "
```

```
15711          LPRINT " "
15720  NEXT J
15730  PRINT:PRINT:LPRINT:LPRINT
15731 PRINT"                     ....PRESS ANY KEY TO CONTINUE"
15732 A$ = INKEY$ : IF A$ = "" THEN GOTO 15732
15734 CLS: PRINT : PRINT
15735 CLOSE #1
15740 '************************************************************************
15750 ' NORMALIZE MODE SHAPES
15760 '************************************************************************
15770 FOR I = 1 TO M
15780  BIG = 0!
15790  FOR J = 1 TO N
15800          IF BIG < PHI(I,J) THEN BIG = PHI(I,J)
15810  NEXT J
15820  FOR J = 1 TO N
15830          PHI(I,J) = PHI(I,J)/BIG
15840  NEXT J
15850 NEXT I
15860 '************************************************************************
15870 ' OUTPUT NORMALIZED MODE SHAPES
15880 '************************************************************************
15890 PRINT"NORMALIZED MODES USED IN ANALYSIS":PRINT :LPRINT
15891 LPRINT"***** N O R M A L I Z E D  M O D E S  F O R  A N A L Y S I S *****"
15892 LPRINT
15900 K = M
15910 IF K > 5 THEN GOTO 15980
15920  FOR J = 1 TO N
15930          FOR I = 1 TO M
15940                  PRINT USING U$; PHI(I,J);
15941                  LPRINT USING U$;PHI(I,J);
15950          NEXT I
15960          PRINT " "
15961          LPRINT " "
15970  NEXT J
15971 PRINT: PRINT"                ....PRESS ANY KEY TO CONTINUE"
15972 A$ = INKEY$ : IF A$ = "" THEN GOTO 15972
15973 CLS
15980   LPRINT : LPRINT : GOTO 16120
15990  FOR J = 1 TO N
16000          FOR I = 1 TO 5
16010                  PRINT USING U$; PHI(I,J);
16011                  LPRINT USING U$; PHI(I,J);
16020          NEXT I
16030          PRINT " "
16031          LPRINT " "
16040  NEXT J
16050  PRINT:PRINT:LPRINT:LPRINT
16051  PRINT"                ....PRESS ANY KEY TO CONTINUE"
16052 A$ = INKEY$ : IF A$ = "" THEN GOTO 15052
16053 CLS
```

```
16060  FOR J = 1 TO N
16070         FOR I = 6 TO N
16080                PRINT USING U$; PHI(I,J);
16081                LPRINT USING U$; PHI(I,J);
16090         NEXT I
16100         PRINT " "
16101         LPRINT " "
16110  NEXT J
16120  PRINT:PRINT:LPRINT:LPRINT
16121 PRINT"                  ....PRESS ANY KEY TO CONTINUE"
16122 A$ = INKEY$ : IF A$ = "" THEN GOTO 16122
16130 CLS : GOSUB 6000
16140 CLS : LOCATE 21,1,0
16150 PRINT
16155 CLS : GOSUB 8000
16160 CLS : GOSUB 8200
16170 CLS : GOSUB 10000
20000 CLS
20010 LOCATE 5,1,0
20020 PRINT"*** YOU MUST FIRST USE THE PROGRAM JACOBI TO SOLVE EIGENVALUE ***"
20030 PRINT"*** PROBLEM.  IT WILL CALCULATE NATURAL FREQUENCIES AND MODE  ***"
20040 PRINT"***   SHAPES THAT CAN THEN BE USED TO RUN THE DDAM PROGRAM.   ***"
20050 PRINT: PRINT: PRINT:
20060 PRINT"     ...... ENTER <F3>JACOBI<RETURN>":PRINT
20070 PRINT"                  <F2>"
20080 STOP
25000 CLS:PRINT"*** USER MAY USE OPTION 4 TO INSTALL HIS/HER SUBROUTINE ***"
25010    PRINT"            *** BEGINNING AT LINE 25000.***"
25020 FOR I = 1 TO 5000 : NEXT I : GOTO 270
```

C. PROGRAM JACOBI - INSTRUCTIONS FOR USE

The following BASIC program may be used as is or modified by the user to solve the Eigenvalue problem once the equations of motion are formulated. It is self explanatory in execution with the exceptions that the A matrix replaces the stiffness matrix and the B matrix replaces the mass matrix. The program only requires that the upper triangle elements of the stiffness matrix be supplied along with the diagonal elements of the mass matrix.

D. PROGRAM JACOBI LISTING (Adapted from ref. 13)

```
4 CLS
5 REM ==CYCLIC JACOBI METHOD==
10 DIM A(10,10), B(10),U(10,10)
19 REM ==INPUT DATA==
20 GOSUB 70
28 REM==INITIALIZE==
30 GOSUB 660
40 GOSUB 9B0
45 REM ==OUTPUT RESULTS==
50 GOSUB 750
60 GOTO 3000
65 REM ==INPUT DATA==
70 PRINT
80 PRINT " CYCLIC JACOBI METHOD"
160 PRINT
180 PRINT
190 PRINT " ENTER THE SIZE OF PROBLEM (i.e. no. of rows)"
200 PRINT
```

```
210 INPUT "N =    "; N
220 LPRINT "PROBLEM DIMENSION = "; N
230 INPUT "NUMBER OF SIGNIFICANT FIGURES =  "; S1
240 LPRINT
250 PRINT
260 PRINT " ENTER THE UPPER TRIANGULAR ELEMENTS OF MATRIX A ( by columns ):"
270 PRINT
280 LPRINT "UPPER ELEMENTS OF MATRIX A ="
290 LPRINT
320 FOR J = 1 TO N
330 PRINT
340 PRINT " ENTER UPPER PART OF COLUMN "; J
350 PRINT
360 FOR I = 1 TO J
370 PRINT "  A(";I;",";J;") = ";
380 INPUT A(I,J)
381 LPRINT " A(";I;",";J;") = "; A(I,J)
382 LPRINT
390 NEXT I
400 PRINT
440 PRINT
450 NEXT J
460 FOR I = 1 TO N
470 I1 = I - 1
480 FOR J = 1 TO I1
490 A(I,J) = A(J,I)
500 NEXT J
510 NEXT I
520 PRINT
530 PRINT " ENTER ELEMENTS OF DIAGONAL MATRIX B:"
531 LPRINT " ELEMENTS OF DIAGONAL MATRIX B "
532 LPRINT
540 PRINT
570 FOR I = 1 TO N
580 PRINT " B(";I;") = ";
590 INPUT B(I)
591 LPRINT " B(";I;") = ";B(I)
600 NEXT I
610 PRINT
611 LPRINT
650 RETURN
655 REM ==INITIALIZE TOLERANCE AND MAX NO. OF ROTATIONS ==
660 Z = 2 * S1
670 T1 = 1/(10^Z)
680 PRINT
690 CLS: PRINT  "TOLERANCE = ";T1
691 LPRINT "TOLERANCE = ";T1
700 R = 5*N*N
710 R1 = 0
720 T2 = .1
730 N1 = N - 1
```

```
740 RETURN
746 REM ==OUTPUT EIGENSOLUTION==
750 PRINT
760 PRINT
770 PRINT "SOLUTION"
771 LPRINT
780 PRINT
781 LPRINT
782 LPRINT "**************** SOLUTION *****************"
783 LPRINT
800 PRINT " NUMBER OF ROTATIONS REQUIRED = ";R1
801 LPRINT "NUMBER OF ROTATIONS REQUIRED = ";R1
802 LPRINT
803 LPRINT
810 PRINT
820 PRINT
830 FOR J = 1 TO N
840 PRINT
850 PRINT " EIGENVALUE ";J;" IS ";B(J)
851 LPRINT "EIGENVALUE ";J;" IS ";B(J)
852 LPRINT
853 LPRINT "ITS EIGENVECTOR IS "
860 PRINT
870 PRINT " ITS EIGENVECTOR IS "
880 PRINT
890 FOR I = 1 TO N
900 PRINT U(I,J)
901 LPRINT U(I,J)
902 LPRINT
910 NEXT I
920 PRINT
921 LPRINT
930 PRINT " PRESS SPACE BAR TO CONTINUE "
940 IF INKEY$ = " " THEN 942
941 GOTO 940
942 CLS
950 PRINT
960 NEXT J
970 RETURN
975 REM ==EIGENPROBLEM SOLUTION==
980 GOSUB 1130
985 REM ==PERFORM ONE CYCLE OF ROTATIONS==
990 GOSUB 1290
995 REM == CHECK TOLERANCE ==
1000 IF X1 < T1 THEN 1110
1005 REM == CHECK NO. OF ROTATIONS ==
1010 IF R1 > R THEN 1040
1020 T2 = .1 * X1
1030 GOTO 990
1040 PRINT
1050 PRINT " *** ERROR ***"
```

```
1051 LPRINT "********************* ERROR *********************"
1060 PRINT
1070 PRINT " NO CONVERGENCE ATTAINED"
1071 LPRINT " NO CONVERGENCE ATTAINED "
1080 PRINT
1081 LPRINT
1090 PRINT " WITH ";R1;" ROTATIONS"
1091 LPRINT " WITH ";R1;" ROTATIONS"
1100 END
1110 GOSUB 1830
1120 RETURN
1130 FOR I = 1 TO N
1140 FOR J = 1 TO N
1150 U(I,J) = 0
1160 NEXT J
1170 U(I,I) = 1
1180 NEXT I
1190 FOR I = 1 TO N
1200 B1 = SQR(B(I))
1210 B(I) = 1 / 81
1220 NEXT I
1230 FOR I = 1 TO N
1240 FOR J = 1 TO N
1250 A(I,J) = B(I) * A(I,J) * 8(J)
1260 NEXT J
1270 NEXT I
1280 RETURN
1290 X1 = 0
1300 FOR K = 1 TO N1
1310 K1 = K + 1
1320 FOR L = K1 TO N
1330 A1 = A(K,K)
1340 A2 = A(K,L)
1350 A3 = A(L,L)
1360 X = A2 * A2 /(A1 * A3)
1365 REM == CHECK IF ROTATION IS NEEDED ==
1370 IF X ) X1 THEN 1390
1380 GOTO 1800
1390  X1 = X
1400 IF X ( T2 THEN 1800
1410 R1 = R1 + 1
1415 REM == COMPUTE ANGLE ==
1420 IF A1 = A3 THEN 1470
1430 Z = .5 * (A1 - A3) /A2
1440 Z1 = 1 + 1/ (Z * Z)
1450 T = -Z * (1 + SQR(Z1))
1460 GOTO 1480
1470 T = 1
1480 C = 1 / SQR( 1 + T * T)
1490 S = C * T
1500 S2 = S * S
```

```
1510 C2 = C * C
1520 A(K,L) = 0
1525 REM == TRANSFORM DIAGONAL ELEMENTS ==
1530 A0 = 2 * A2 * C * S
1540 A(K,K) = A1 *C2 + A0 + A3 * S2
1550 A(L,L) = A1 * S2 - A0 + A3 * C2
1555 REM == TRANSFORM OFF DIAGONAL ELEMENTS ==
1560 FOR I = 1 TO N
1570 IF I < K THEN 1600
1580 IF I > K THEN 1640
1590 GOTO 1740
1600 A0 = A(I,K)
1610 A(I,K) = C * A0 + S * A(I,L)
1620 A(I,L) = -S * A0 + C * A(I,L)
1630 GOTO 1740
1640 IF I < L THEN 1670
1650 IF I > L THEN 1710
1660 GOTO 1740
1670 A0 = A(K,I)
1680 A(K,I) = C * A0 + S * A(I,L)
1690 A(I,L) = -S * A0 + C * A(I,L)
1700 GOTO 1740
1710 A0 = A(K,I)
1720 A(K,I) = C * A0 + S * A(L,I)
1730 A(L,I) = -S * A0 + C * A(L,I)
1740 NEXT I
1745 REM == TRANSFORM MATRIX U TO GENERATE EIGENVECTORS ==
1750 FOR I = 1 TO N
1760 U0 = U(I,K)
1770 U(I,K) = C * U0 + S * U(I,L)
1780 U(I,L) = -S * U0 + C * U(I,L)
1790 NEXT I
1800 NEXT L
1810 NEXT K
1820 RETURN
1825 REM == NORMALIZE EIGENVECTORS ==
1830 FOR I = 1 TO N
1840 FOR J = 1 TO N
1850 U(I,J) = U(I,J) * B(I)
1860 NEXT J
1870 NEXT I
1880 FOR I = 1 TO N
1890 B(I) = A(I,I)
1900 NEXT I
1905 REM == ORDER EIGENSOLUTION ==
1910 FOR I = 1 TO N1
1920 I1 = I + 1
1930 Z = B(I)
1940 M = I
1950 FOR J = I1 TO N
1960 IF Z < B(J) THEN 1990
```

```
1970 Z = B(J)
1980 M = J
1990 NEXT J
2000 B(M) = B(I)
2010 B(I) = Z
2020 FOR J = 1 TO N
2030 Z = U(J,I)
2040 U(J,I) = U(J,M)
2050 U(J,M) = Z
2060 NEXT J
2070 NEXT I
2080 RETURN
3000 PRINT " END OF PROGRAM "
3010 END
```

APPENDIX B: PROGRAMS USED TO CONVERT VELOCITY HISTORIES TO DEFLECTION HISTORIES

```
10 '--------------------------------------------------------------------------
20 '    PROGRAM ** SIMPS1 ** USED FOR CASE I
30 '    INTEGRATES VELOCITY HISTORY WRT TIME TO OBTAIN DEFLECTIONS
40 '--------------------------------------------------------------------------
50 CLS : DIM A$(3)
60 F(1)=0 : F(2)=0 : F(3)=0 : FORM1$=" #.####   " : FORM2$=" ##.######  "
70 INPUT" ENTER THE NAME OF AN INPUT FILE................. ",FILEIN$ : PRINT
80 INPUT" ENTER THE ORDINATES TO INTEGRATE OVER........... ",NUMBER : PRINT
90 INPUT" ENTER THE SIZE OF THE INTEGRATION INTERVAL...... ",H
100 CLS
110 OPEN FILEIN$ FOR INPUT AS #1 : OPEN "DISPR2.OUT" FOR OUTPUT AS #2
120 '-------------------------------------------------------------------------
130 '    USE SIMPSON'S 1/3 RULE TO CALCULATE DEFLECTIONS
140 '-------------------------------------------------------------------------
150 INPUT #1,M,TIME(0),VEL11(0),VEL12(0),VEL13(0),VEL61(0),VEL62(0),VEL63(0)
160 FOR I = 1 TO 2
170     INPUT #1,M,TIME(I),VEL11(I),VEL12(I),VEL13(I),VEL61(I),VEL62(I),VEL63(I)
180 NEXT I
190 V1A = VEL61(0) - VEL11(0)
200 V1B = VEL61(1) - VEL11(1)
210 V1C = VEL61(2) - VEL11(2)
220 Q1  = (V1A + 4*V1B + V1C) * H / 3
230 V2A = VEL62(0) - VEL12(0)
240 V2B = VEL62(1) - VEL12(1)
250 V2C = VEL62(2) - VEL12(2)
260 Q2  = (V2A + 4*V2B + V2C) * H / 3
270 V3A = VEL63(0) - VEL13(0)
280 V3B = VEL63(1) - VEL13(1)
290 V3C = VEL63(2) - VEL13(2)
300 Q3  = (V3A + 4*V3B + V3C) * H / 3
310 F(1) = F(1) + Q1
320 F(2) = F(2) + Q2
330 F(3) = F(3) + Q3
340 T   = TIME(1) * 1000
350 FOR I = 1 TO 3
360     IF ABS(QMAX(I)) ) ABS(F(I)) THEN GOTO 380
370             QMAX(I) = F(I) : TMAX(I) = T
380 NEXT I
390 PRINT #2, " T =  ";: PRINT #2, USING FORM1$;T;
400 PRINT #2, "msec    DX = "; : PRINT #2, USING FORM2$;F(1);
410 PRINT #2, "in.    DY = ";:   PRINT #2, USING FORM2$;F(2);
420 PRINT #2, "in.    DZ = ";:   PRINT #2, USING FORM2$;F(3);:PRINT #2,"in."
430 VEL11(0) = VEL11(2) : VEL12(0) = VEL12(2) : VEL13(0) = VEL13(2)
```

```
440 VEL61(0) = VEL61(2) : VEL62(0) = VEL62(2) : VEL63(0) = VEL63(2)
450 IF M + 2 < NUMBER THEN GOTO 160
460 A$(1) = "(X) = " : A$(2) = "(Y) = " : A$(3) = "(Z) = "
470 FOR I = 1 TO 3
480     PRINT #2, "TMAX";A$(I); : PRINT #2, USING FORM1$;TMAX(I);
485     PRINT #2," msec  DMAX";A$(I);: PRINT #2, USING FORM2$;QMAX(I);
486     PRINT #2," in."
490 NEXT I
500 CLOSE #1 : CLOSE #2
```

```
10 '---------------------------------------------------------------------------
20 '    PROGRAM ** SIMPS2 ** USED FOR CASES II AND III
30 '    INTEGRATES VELOCITY HISTORY WRT TIME TO OBTAIN DEFLECTIONS
40 '---------------------------------------------------------------------------
50 CLS : DIM A$(3)
60 F(1)=0 : F(2)=0 : FORM1$=" ##.####   " : FORM2$=" ##.######  "
70 INPUT" ENTER THE NAME OF AN INPUT FILE................. ",FILEIN$ : PRINT
80 INPUT" ENTER THE ORDINATES TO INTEGRATE OVER........... ",NUMBER : PRINT
90 INPUT" ENTER THE SIZE OF THE INTEGRATION INTERVAL...... ",H
100 CLS
110 OPEN FILEIN$ FOR INPUT AS #1 : OPEN "DISPR2.OUT" FOR OUTPUT AS #2
115 PRINT #2,"H = ";H;" SEC"
120 '--------------------------------------------------------------------------
130 '    USE SIMPSON'S 1/3 RULE TO CALCULATE DEFLECTIONS
140 '--------------------------------------------------------------------------
150 INPUT #1,M,TIME(0),VEL12(0),VEL92(0),VEL52(0),VEL112(0),VEL192(0),VEL152(0)
160 FOR I = 1 TO 2
170     INPUT #1,M,TIME(I),VEL12(I),VEL92(I),VEL52(I),VEL112(I),VEL192(I),VEL152(I)
180 NEXT I
190 V1A = (VEL12(0) + VEL92(0))/2 - VEL52(0)
200 V1B = (VEL12(1) + VEL92(1))/2 - VEL52(1)
210 V1C = (VEL12(2) + VEL92(2))/2 - VEL52(2)
220 Q1  = (V1A + 4*V1B + V1C) * H / 3
230 V2A = (VEL112(0) + VEL192(0))/2 - VEL152(0)
240 V2B = (VEL112(1) + VEL192(1))/2 - VEL152(1)
250 V2C = (VEL112(2) + VEL192(2))/2 - VEL152(2)
260 Q2  = (V2A + 4*V2B + V2C) * H / 3
310 F(1) = F(1) + Q1
320 F(2) = F(2) + Q2
340 T   = TIME(1) * 1000
350 FOR I = 1 TO 2
360     IF ABS(QMAX(I)) > ABS(F(I)) THEN GOTO 380
370              QMAX(I) = F(I) : TMAX(I) = T
380 NEXT I
390 PRINT #2, " T =  ";: PRINT #2, USING FORM1$;T;
400 PRINT #2, "msec    D(5,Y) = "; : PRINT #2, USING FORM2$;F(1);
```

```
410 PRINT #2, "in.    D(15,Y) = ";:   PRINT #2, USING FORM2$;F(2);
420 PRINT #2, "in."
430 VEL12(0) = VEL12(2) : VEL92(0) = VEL92(2) : VEL52(0) = VEL52(2)
440 VEL112(0) = VEL112(2) : VEL192(0) = VEL192(2) : VEL152(0) = VEL152(2)
450 IF M + 3 < NUMBER THEN GOTO 160
460 A$(1) = "(5,Y) = " : A$(2) = "(15,Y) = "
470 FOR I = 1 TO 2
480     PRINT #2, "TMAX";A$(I); : PRINT #2, USING FORM1$;TMAX(I);
485     PRINT #2," msec  DMAX";A$(I);: PRINT #2, USING FORM2$;DMAX(I);
486     PRINT #2," in."
490 NEXT I
500 CLOSE #1 : CLOSE #2
```

APPENDIX C - TYPICAL CASE I ANALYSIS

As noted in Chapter V, the first step in each analysis was the construction of an appropriate SAPIV model of the equipment substructure under consideration. In this case, the model represents a 1,000 lb valve attached to the free end of a cantilever foundation.

A. SAPIV INPUT DATA FOR CASE I

The following data file was used to generate the modal information for the Case I model [Ref. 10].

HEADING CARD

```
CASE 1 -- VALVE ON CANTILEVER FOUNDATION
```

MASTER CONTROL CARD

```
7,1,0,6,1,0,0,0,0,0
```

NODAL PT DATA

```
0,1,1,0,0,1,1,1,0.,0.,0.,1,0.0
0,2,1,0,0,0,1,1,0.,0.,5.,1,0.0
0,6,1,0,0,0,1,1,0.,0.,25.,1,0.0
0,7,1,1,1,1,1,1,10.,0.,10.,0.0
```

TYPE 2 - 3D BEAM ELEMENTS

```
2,5,1,0,1
```

MATERIAL PROPERTIES

```
1,30.0E6,0.3,7.29E-4,0.0
```

ELEMENT PROPERTY CARD

```
1,17.64,0.0,0.0,539.95,333.95,206.0
```

```
      0.0,0.0,0.0,0.0
      0.0,0.0,0.0,0.0
      0.0,0.0,0.0,0.0
      0.0,0.0,0.0,0.0

BEAM DATA CARDS

      1,1,2,7,1,1,0,0,0,0,000000,1
      5,5,6,7,1,1,0,0,0,0,000000,1

CONCENTRATED MASS ON FREE END

      6,0,2.591,2.591,2.591,0.0,0.0,0.0
      0,0,0.000,0.000,0.000,0.0,0.0,0.0

DYNAMIC ANALYSIS CARD (IN ACCORDANCE WITH REF.4

      0,0,0,0.0,0.0,0,0.0
      1,0
      1,1,1,1,1,1,1

END OF DATA (DUMMY TITLE CARD)
0,0,0,0,0,0,0,0,0,0
```

The output from the SAPIV code is not included here but all the essential information is included in the USLOB code output.

B. PICRUST INPUT DATA FOR CASE I

The PICRUST code is used to process the SAPIV output and calculate influence coefficients corresponding to the base or support motions of the substructure. Additionally, connectivity between the hull and foundation is specified and a substructure file is produced.

The following input file was used for CASE I:

```
LIST OPTIONS

      1,1,1,1,0,1,1,1,0,0
      0,1,1,1,1,1,0,1,0,0

MODAL SPECIFICATION
```

```
5,0,0
```

CONNECTIVITY

```
1,5,10
270
```

MODES FROM SAPIV INCLUDED IN ANALYSIS

```
1,2,3,4,5
```

END

The output listing from the PICRUST code is not included here but all essential output from these calculations is included in the USLOB output.

C. USLOB INPUT DATA FOR CASE I (1414" STANDOFF)

The following input data was supplied to the USLOB code to specify the parameters for the time integration and associated output. A total of 1201 time steps are specified for the integration interval, each covering an interval of 5.0E-6 seconds. The XXXX parameters denote parameters for eq. 5 which are ommitted due to the sensitivity of this equation.

The following input data correspond to the USLOB output included in this appendix.

TIME STEP AND CONTROL CARD FOR INTEGRATION

```
1201,1,1,9,11,1,1
```

EQUATION (5) PARAMETER SPECIFICATION

```
5.0E-6,XXXX,1606,0.0
5000.,XXXX,XXXX,XXXX,XXXX
```

```
OUTPUT OPTIONS

      0,1,0,0,0,0,0,0,1,0
      0,0,1,1,0,0,0,1,0,0

SHELL VELOCITY OUTPUTS AT EACH TIME STEP

      1,5,10

SUBSTRUCTURE VELOCITY OUTPUTS AT EACH TIME STEP

      6
      1,1,1,2,1,3,6,1,6,2,6,3
      (This notation specifies the x,y,z translations of the
      base and tip nodes of the substructure respectively.)

END
```

D. LISTING - USLOB OUTPUT FOR CASE 1

```
 CASE 1 -- VALVE ON FOUNDATION VERT DISPL


 CONTROL PARAMETERS FOR SUBSTRUCTURE    1

 NPOINT =     7       NDOF =    18
  NCDOF =     3      NUDOF =    15
  NFREQ =    10      NFACE =     1
 NSYMTY =     0     NFORCE =    13


 CONNECTION DATA FOR INTERFACE POINTS

    SHL   SUB     X     Y     Z    XX    YY    ZZ LSGPT LFIND      DEGCON
     56     1     1     1     1     0     0     0  5010    27  2.700000E+02
0DEGROT =  9.000000E+01

1EQUATION NUMBERS FOR SUBSTRUCTURE    1

 POINT    X    Y    Z   XX   YY   ZZ
     1    1    2    3    0    0    0
     2    4    5    6    0    0    0
     3    7    8    9    0    0    0
     4   10   11   12    0    0    0
     5   13   14   15    0    0    0
     6   16   17   18    0    0    0
     7    0    0    0    0    0    0


 FIXED-BASE NATURAL FREQUENCIES FOR SUBSTRUCTURE    1

  MODE       FREQ      MODE       FREQ      MODE       FREQ      MODE       FREQ
     1  4.45541E+02      2  1.05485E+03      3  1.34307E+03      4  4.03705E+03
     5  7.60871E+03      6  9.55805E+03      7  1.04549E+04      8  1.21696E+04
     9  1.22840E+04     10  1.80142E+04

1COMPACTED FIXED-BASE MODES FOR SUBSTRUCTURE    1

              1           2           3           4           5
    1  1.9139E-18 -1.2402E-01  9.5490E-10  6.2397E-12  2.4775E-11
    2  3.1568E-20  8.9711E-09  1.2402E-01  1.1183E-12  1.6989E-13
    3 -1.2402E-01 -4.8508E-20  3.7107E-11 -1.4719E+00 -2.3705E+00
    4  3.8186E-18 -2.4745E-01  1.9053E-09  1.0036E-11  3.9865E-11
    5  6.2987E-20  1.7900E-08  2.4745E-01  1.8006E-12  2.7333E-13
    6 -2.4745E-01 -9.6785E-20  5.9702E-11 -2.3685E+00 -1.4497E+00
    7  5.7052E-18 -3.6971E-01  2.8465E-09  9.9080E-12  3.9373E-11
    8  9.4105E-20  2.6743E-08  3.6971E-01  1.7811E-12  2.6992E-13
  9 -3.6971E-01 -1.4460E-19  5.8957E-11 -2.3393E+00  1.4839E+00
 10  7.5646E-18 -4.9020E-01  3.7743E-09  5.9093E-12  2.3492E-11
 11  1.2478E-19  3.5459E-08  4.9020E-01  1.0677E-12  1.6103E-13
 12 -4.9020E-01 -1.9173E-19  3.5172E-11 -1.3957E+00  2.3572E+00
 13  9.3880E-18 -6.0836E-01  4.6840E-09 -3.9555E-13 -1.5718E-12
 14  1.5485E-19  4.4006E-08  6.0836E-01 -5.9949E-14 -1.0775E-14
 15 -6.0836E-01 -2.3794E-19 -2.3536E-12  9.3383E-02 -4.2362E-02

            6           7           8           9          10
  1  1.4719E+00  3.5420E-14  1.2133E-20  1.2095E-12 -2.3705E+00
  2  1.3626E-13  2.2993E-11 -1.4719E+00  6.6535E-13  9.7987E-11
  3  2.4183E-10 -2.3685E+00 -3.3664E-12 -1.4634E+00 -1.8812E-12
  4  2.3685E+00  5.3840E-14  1.5886E-20 -7.6500E-13 -1.4497E+00
  5  2.1925E-13  3.6999E-11 -2.3685E+00  1.0680E-12  5.7223E-11
  6 -1.5016E-10  1.4719E+00  5.4501E-12  2.3693E+00 -3.7449E-12
  7  2.3393E+00  4.9358E-14  1.1252E-20 -4.6836E-12  1.4839E+00
  8  2.1655E-13  3.6543E-11 -2.3393E+00  1.0516E-12 -6.8350E-11
  9 -1.4869E-10  1.4538E+00 -5.4572E-12 -2.3724E+00 -5.6047E-12
 10  1.3957E+00  2.7551E-14  4.4918E-21 -6.5906E-12  2.3572E+00
 11  1.2920E-13  2.1803E-11 -1.3957E+00  6.2577E-13 -1.0703E-10
 13  2.4276E-10 -2.3754E+00  3.3850E-12  1.4715E+00 -7.4239E-12
 14 -9.3383E-02 -1.9932E-15 -4.7535E-22 -5.2983E-12 -4.2362E-02
 15 -8.6446E-15 -1.4588E-12  9.3383E-02 -4.1996E-14 -7.7491E-12
 16 -2.2910E-12  2.2420E-02 -2.3083E-14 -1.0035E-02 -9.2163E-12


1SUBSTRUCTURE CONTROL PARAMETERS

    SUB  NFREQ   NDOF  NCDOF   NPTS   LOCQ   NEQB NBLOCK NROWFC
      1     10     18      3      7    518     15      1      3
   NBLFOR KOLBAR NBLBAR BEGFRQ BEGSBL BEGBAR BEGFOR
      1    254      1      1      1      1      1

 CONTROL PARAMETERS FOR SOLUTION

  NTIME =  1201        NEQS =   638
  NSKIP =     2       NRECS =   601
  NCHRG =     1      NTHETA =    17
  NQUAD =     9      NDELTA =    21
  NFINE =    11       NQDOT =   264
 KOUPLE =     2       NSUBS =     1


 SOLUTION PARAMETERS

 TOTALM =  3.541492E+04       AREA =  3.639044E+06
 RHOFLU =  9.452160E-05       CFLU =  6.000000E+04
   DELT =  5.000000E-06       TEND =  6.000000E-03
  XLOAD =  8.844880E+02      STOFF =  1.414000E+03
  RLOAD =  1.606000E+03     ORNRAD =  0.
 DATA FOR EMPIRICAL PRESSURE-TIME HISTORY

  WCHRG =  5.000000E+03      SURCUT =  XXXXXXXXXXXX
  PZMLT =  XXXXXXXXXXXX       THMLT =  XXXXXXXXXXXX
  PZEXP =  XXXXXXXXXXXX       THEXP =  XXXXXXXXXXXX

1VELOCITY DISTRIBUTION AT SHELL STATION   56   (SEGMENT    5   POINT   10)


  STEP     TIME      WDOT(  0)   WDOT( 90)   WDOT(180)   WDOT(270)

     1  0.          0.          0.          0.          0.
     3  1.0000E-05  4.9444E-01  7.5446E-02  1.7639E-01  7.5445E-02
     5  2.0000E-05  1.8855E+00  2.8722E-01  6.5644E-01  2.8720E-01
     7  3.0000E-05  3.8391E+00  5.8420E-01  1.3005E+00  5.8410E-01
     9  4.0000E-05  6.1484E+00  9.3465E-01  2.0219E+00  9.3436E-01
    11  5.0000E-05  8.6881E+00  1.3193E+00  2.7669E+00  1.3186E+00
    13  6.0000E-05  1.1347E+01  1.7214E+00  3.4983E+00  1.7202E+00
    15  7.0000E-05  1.4145E+01  2.1416E+00  4.2275E+00  2.1397E+00
    17  8.0000E-05  1.7083E+01  2.5792E+00  4.9559E+00  2.5763E+00
    19  9.0000E-05  2.0102E+01  3.0265E+00  5.6665E+00  3.0224E+00
    21  1.0000E-04  2.3241E+01  3.4895E+00  6.3713E+00  3.4840E+00
    23  1.1000E-04  2.6547E+01  3.9697E+00  7.0994E+00  3.9625E+00
    25  1.2000E-04  2.9933E+01  4.4593E+00  7.8237E+00  4.4502E+00
    27  1.3000E-04  3.3481E+01  4.9651E+00  8.5656E+00  4.9539E+00
    29  1.4000E-04  3.7123E+01  5.4786E+00  9.3141E+00  5.4650E+00
    31  1.5000E-04  4.0922E+01  6.0054E+00  1.0091E+01  5.9891E+00
    33  1.6000E-04  4.4771E+01  6.5359E+00  1.0856E+01  6.5167E+00
    35  1.7000E-04  4.8745E+01  7.0707E+00  1.1647E+01  7.0482E+00
    37  1.8000E-04  5.2721E+01  7.6048E+00  1.2411E+01  7.5788E+00
    39  1.9000E-04  5.6819E+01  8.1394E+00  1.3200E+01  8.1097E+00
    41  2.0000E-04  6.0891E+01  8.6690E+00  1.3957E+01  8.6353E+00
    43  2.1000E-04  6.5036E+01  9.1899E+00  1.4723E+01  9.1519E+00
    45  2.2000E-04  6.9161E+01  9.7044E+00  1.5459E+01  9.6618E+00
    47  2.3000E-04  7.3292E+01  1.0209E+01  1.6185E+01  1.0161E+01
    49  2.4000E-04  7.7437E+01  1.0700E+01  1.6899E+01  1.0648E+01
    51  2.5000E-04  8.1493E+01  1.1180E+01  1.7569E+01  1.1122E+01
    53  2.6000E-04  8.5606E+01  1.1643E+01  1.8247E+01  1.1580E+01
    55  2.7000E-04  8.9672E+01  1.2097E+01  1.8895E+01  1.2027E+01
    57  2.8000E-04  9.3669E+01  1.2528E+01  1.9509E+01  1.2451E+01
    59  2.9000E-04  9.7634E+01  1.2918E+01  2.0106E+01  1.2835E+01
    61  3.0000E-04  1.0154E+02  1.3301E+01  2.0669E+01  1.3209E+01
    63  3.1000E-04  1.0542E+02  1.3669E+01  2.1219E+01  1.3570E+01
    65  3.2000E-04  1.0933E+02  1.4026E+01  2.1774E+01  1.3918E+01
    67  3.3000E-04  1.1317E+02  1.4379E+01  2.2300E+01  1.4261E+01
    69  3.4000E-04  1.1701E+02  1.4712E+01  2.2828E+01  1.4585E+01
    71  3.5000E-04  1.2086E+02  1.5034E+01  2.3353E+01  1.4896E+01
    73  3.6000E-04  1.2465E+02  1.5354E+01  2.3858E+01  1.5205E+01
    75  3.7000E-04  1.2846E+02  1.5655E+01  2.4379E+01  1.5494E+01
    77  3.8000E-04  1.3226E+02  1.5940E+01  2.4892E+01  1.5767E+01
 79  3.9000E-04  1.3599E+02  1.6222E+01  2.5382E+01  1.6036E+01
 81  4.0000E-04  1.3974E+02  1.6490E+01  2.5884E+01  1.6291E+01
 83  4.1000E-04  1.4349E+02  1.6740E+01  2.6395E+01  1.6526E+01
 85  4.2000E-04  1.4719E+02  1.6987E+01  2.6885E+01  1.6759E+01
 87  4.3000E-04  1.5086E+02  1.7222E+01  2.7371E+01  1.6979E+01
 89  4.4000E-04  1.5454E+02  1.7432E+01  2.7866E+01  1.7174E+01
 91  4.5000E-04  1.5817E+02  1.7639E+01  2.8350E+01  1.7365E+01
 93  4.6000E-04  1.6175E+02  1.7843E+01  2.8822E+01  1.7553E+01
 95  4.7000E-04  1.6533E+02  1.8017E+01  2.9304E+01  1.7710E+01
 97  4.8000E-04  1.6888E+02  1.8180E+01  2.9778E+01  1.7856E+01
 99  4.9000E-04  1.7237E+02  1.8342E+01  3.0233E+01  1.8000E+01
101  5.0000E-04  1.7580E+02  1.8487E+01  3.0677E+01  1.8127E+01
103  5.1000E-04  1.7920E+02  1.8601E+01  3.1125E+01  1.8223E+01
105  5.2000E-04  1.8255E+02  1.8714E+01  3.1550E+01  1.8317E+01
107  5.3000E-04  1.8585E+02  1.8824E+01  3.1964E+01  1.8408E+01
109  5.4000E-04  1.8910E+02  1.8900E+01  3.2371E+01  1.8463E+01
111  5.5000E-04  1.9229E+02  1.8957E+01  3.2765E+01  1.8501E+01
113  5.6000E-04  1.9540E+02  1.9013E+01  3.3136E+01  1.8537E+01
115  5.7000E-04  1.9845E+02  1.9063E+01  3.3489E+01  1.8565E+01
117  5.8000E-04  2.0147E+02  1.9071E+01  3.3847E+01  1.8552E+01
119  5.9000E-04  2.0442E+02  1.9074E+01  3.4182E+01  1.8533E+01
121  6.0000E-04  2.0730E+02  1.9076E+01  3.4496E+01  1.8512E+01
123  6.1000E-04  2.1010E+02  1.9057E+01  3.4789E+01  1.8471E+01
125  6.2000E-04  2.1283E+02  1.8995E+01  3.5074E+01  1.8386E+01
127  6.3000E-04  2.1550E+02  1.8932E+01  3.5335E+01  1.8300E+01
129  6.4000E-04  2.1811E+02  1.8869E+01  3.5583E+01  1.8213E+01
131  6.5000E-04  2.2067E+02  1.8790E+01  3.5823E+01  1.8110E+01
133  6.6000E-04  2.2317E+02  1.8681E+01  3.6056E+01  1.7978E+01
135  6.7000E-04  2.2563E+02  1.8572E+01  3.6277E+01  1.7844E+01
137  6.8000E-04  2.2805E+02  1.8463E+01  3.6484E+01  1.7711E+01
139  6.9000E-04  2.3041E+02  1.8340E+01  3.6682E+01  1.7564E+01
141  7.0000E-04  2.3271E+02  1.8189E+01  3.6873E+01  1.7389E+01
143  7.1000E-04  2.3497E+02  1.8035E+01  3.7054E+01  1.7211E+01
145  7.2000E-04  2.3719E+02  1.7882E+01  3.7222E+01  1.7034E+01
147  7.3000E-04  2.3936E+02  1.7723E+01  3.7379E+01  1.6851E+01
149  7.4000E-04  2.4147E+02  1.7531E+01  3.7534E+01  1.6635E+01
151  7.5000E-04  2.4354E+02  1.7336E+01  3.7676E+01  1.6415E+01
153  7.6000E-04  2.4558E+02  1.7146E+01  3.7806E+01  1.6201E+01
155  7.7000E-04  2.4757E+02  1.6961E+01  3.7924E+01  1.5993E+01
157  7.8000E-04  2.4950E+02  1.6736E+01  3.8042E+01  1.5744E+01
159  7.9000E-04  2.5139E+02  1.6504E+01  3.8147E+01  1.5489E+01
161  8.0000E-04  2.5325E+02  1.6279E+01  3.8242E+01  1.5240E+01
163  8.1000E-04  2.5508E+02  1.6062E+01  3.8326E+01  1.5001E+01
165  8.2000E-04  2.5685E+02  1.5809E+01  3.8407E+01  1.4725E+01
167  8.3000E-04  2.5857E+02  1.5546E+01  3.8481E+01  1.4440E+01
169  8.4000E-04  2.6026E+02  1.5290E+01  3.8542E+01  1.4161E+01
171  8.5000E-04  2.6193E+02  1.5039E+01  3.8594E+01  1.3888E+01
173  8.6000E-04  2.6355E+02  1.4778E+01  3.8640E+01  1.3606E+01
175  8.7000E-04  2.6510E+02  1.4488E+01  3.8680E+01  1.3294E+01
177  8.8000E-04  2.6663E+02  1.4200E+01  3.8710E+01  1.2985E+01
179  8.9000E-04  2.6813E+02  1.3917E+01  3.8730E+01  1.2682E+01
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181  9.0000E-04  2.6961E+02  1.3643E+01  3.8739E+01  1.2388E+01
183  9.1000E-04  2.7102E+02  1.3335E+01  3.8746E+01  1.2060E+01
185  9.2000E-04  2.7238E+02  1.3019E+01  3.8746E+01  1.1725E+01
187  9.3000E-04  2.7372E+02  1.2709E+01  3.8734E+01  1.1397E+01
189  9.4000E-04  2.7505E+02  1.2406E+01  3.8713E+01  1.1077E+01
191  9.5000E-04  2.7633E+02  1.2100E+01  3.8686E+01  1.0754E+01
193  9.6000E-04  2.7755E+02  1.1765E+01  3.8652E+01  1.0403E+01
195  9.7000E-04  2.7873E+02  1.1429E+01  3.8608E+01  1.0052E+01
197  9.8000E-04  2.7991E+02  1.1100E+01  3.8552E+01  9.7097E+00
199  9.9000E-04  2.8106E+02  1.0778E+01  3.8489E+01  9.3739E+00
201  1.0000E-03  2.8216E+02  1.0442E+01  3.8421E+01  9.0253E+00
203  1.0100E-03  2.8320E+02  1.0089E+01  3.8346E+01  8.6604E+00
205  1.0200E-03  2.8423E+02  9.7388E+00  3.8257E+01  8.2991E+00
207  1.0300E-03  2.8524E+02  9.3938E+00  3.8163E+01  7.9440E+00
209  1.0400E-03  2.8623E+02  9.0548E+00  3.8061E+01  7.5959E+00
211  1.0500E-03  2.8715E+02  8.7064E+00  3.7956E+01  7.2392E+00
213  1.0600E-03  2.8802E+02  8.3494E+00  3.7849E+01  6.8749E+00
215  1.0700E-03  2.8887E+02  7.9933E+00  3.7734E+01  6.5125E+00
217  1.0800E-03  2.8971E+02  7.6462E+00  3.7611E+01  6.1599E+00
219  1.0900E-03  2.9054E+02  7.3036E+00  3.7480E+01  5.8128E+00
221  1.1000E-03  2.9130E+02  6.9413E+00  3.7345E+01  5.4468E+00
223  1.1100E-03  2.9201E+02  6.5667E+00  3.7206E+01  5.0696E+00
225  1.1200E-03  2.9272E+02  6.1998E+00  3.7058E+01  4.7009E+00
227  1.1300E-03  2.9342E+02  5.8414E+00  3.6898E+01  4.3419E+00
229  1.1400E-03  2.9411E+02  5.4887E+00  3.6729E+01  3.9896E+00
231  1.1500E-03  2.9473E+02  5.1168E+00  3.6555E+01  3.6193E+00
233  1.1600E-03  2.9531E+02  4.7374E+00  3.6375E+01  3.2426E+00
235  1.1700E-03  2.9589E+02  4.3669E+00  3.6185E+01  2.8762E+00
237  1.1800E-03  2.9646E+02  4.0038E+00  3.5985E+01  2.5183E+00
239  1.1900E-03  2.9703E+02  3.6475E+00  3.5777E+01  2.1684E+00
241  1.2000E-03  2.9752E+02  3.2711E+00  3.5571E+01  1.7998E+00
243  1.2100E-03  2.9796E+02  2.8911E+00  3.5359E+01  1.4288E+00
245  1.2200E-03  2.9841E+02  2.5193E+00  3.5138E+01  1.0673E+00
247  1.2300E-03  2.9886E+02  2.1528E+00  3.4909E+01  7.1232E-01
249  1.2400E-03  2.9929E+02  1.7896E+00  3.4676E+01  3.6192E-01
251  1.2500E-03  2.9966E+02  1.4168E+00  3.4442E+01  3.2035E-03
253  1.2600E-03  2.9999E+02  1.0388E+00  3.4205E+01 -3.5943E-01
255  1.2700E-03  3.0031E+02  6.6715E-01  3.3959E+01 -7.1455E-01
257  1.2800E-03  3.0063E+02  2.9858E-01  3.3707E+01 -1.0653E+00
259  1.2900E-03  3.0094E+02 -6.5765E-02  3.3451E+01 -1.4107E+00
261  1.3000E-03  3.0121E+02 -4.3242E-01  3.3190E+01 -1.7571E+00
263  1.3100E-03  3.0142E+02 -8.0686E-01  3.2925E+01 -2.1101E+00
265  1.3200E-03  3.0164E+02 -1.1766E+00  3.2647E+01 -2.4572E+00
267  1.3300E-03  3.0185E+02 -1.5432E+00  3.2363E+01 -2.8000E+00
269  1.3400E-03  3.0206E+02 -1.9046E+00  3.2070E+01 -3.1364E+00
271  1.3500E-03  3.0225E+02 -2.2646E+00  3.1774E+01 -3.4702E+00
273  1.3600E-03  3.0236E+02 -2.6320E+00  3.1478E+01 -3.8104E+00
275  1.3700E-03  3.0246E+02 -2.9962E+00  3.1175E+01 -4.1462E+00
277  1.3800E-03  3.0256E+02 -3.3570E+00  3.0869E+01 -4.4775E+00
279  1.3900E-03  3.0267E+02 -3.7125E+00  3.0553E+01 -4.8023E+00
281  1.4000E-03  3.0278E+02 -4.0645E+00  3.0233E+01 -5.1225E+00
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  283  1.4100E-03  3.0280E+02 -4.4214E+00  2.9917E+01 -5.4463E+00
  285  1.4200E-03  3.0230E+02 -4.7756E+00  2.9599E+01 -5.7662E+00
  287  1.4300E-03  3.0279E+02 -5.1262E+00  2.9276E+01 -6.0813E+00
  289  1.4400E-03  3.0280E+02 -5.4737E+00  2.8944E+01 -6.3920E+00
  291  1.4500E-03  3.0281E+02 -5.8180E+00  2.8606E+01 -6.6982E+00
  293  1.4600E-03  3.0277E+02 -6.1611E+00  2.8263E+01 -7.0021E+00
  295  1.4700E-03  3.0267E+02 -6.5018E+00  2.7936E+01 -7.3024E+00
  297  1.4800E-03  3.0257E+02 -6.8409E+00  2.7599E+01 -7.5999E+00
  299  1.4900E-03  3.0247E+02 -7.1776E+00  2.7255E+01 -7.8941E+00
  301  1.5000E-03  3.0239E+02 -7.5121E+00  2.6903E+01 -8.1850E+00
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(This history is abbreviated for illustrative purposes.)

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1VELOCITY DISTRIBUTION ALONG SUBSTRUCTURE     1

 STEP     TIME      VEL(  1,1)  VEL(  1,2)  VEL(  1,3)  VEL(  6,1)  VEL(  6,2)  VEL(  6,3)
    1  0.          0.          0.          0.          0.          0.          0.
    3  1.0000E-05 -7.6928E-04 -6.4008E-03  7.5445E-02  6.6872E-07 -1.9765E-05 -4.3588E-14
    5  2.0000E-05 -3.6167E-03 -2.0700E-02  2.8720E-01  1.9028E-06 -3.3974E-05  1.4181E-12
    7  3.0000E-05 -8.8040E-03 -3.3246E-02  5.8410E-01  1.6589E-06  1.2365E-05  3.8135E-10
    9  4.0000E-05 -1.6429E-02 -3.7045E-02  9.3436E-01 -3.5152E-08  4.4999E-05  1.3005E-08
   11  5.0000E-05 -2.6541E-02 -2.6866E-02  1.3186E+00 -4.3943E-06 -1.6797E-04  1.8281E-07
   13  6.0000E-05 -3.8720E-02  3.0282E-04  1.7202E+00 -2.8589E-05 -9.1328E-04  1.5070E-06
   15  7.0000E-05 -5.2809E-02  4.4051E-02  2.1397E+00 -1.2167E-04 -2.3440E-03  8.6295E-06
   17  8.0000E-05 -6.8819E-02  1.0709E-01  2.5763E+00 -3.7008E-04 -4.2651E-03  3.7798E-05
   19  9.0000E-05 -8.6191E-02  1.8835E-01  3.0224E+00 -8.8620E-04 -6.0883E-03  1.3459E-04
   21  1.0000E-04 -1.0522E-01  2.9143E-01  3.4840E+00 -1.7841E-03 -6.8775E-03  4.0597E-04
   23  1.1000E-04 -1.2514E-01  4.1250E-01  3.9625E+00 -3.1660E-03 -5.5941E-03  1.0680E-03
   25  1.2000E-04 -1.4552E-01  5.5122E-01  4.4502E+00 -5.1171E-03 -1.2343E-03  2.5041E-03
   27  1.3000E-04 -1.6745E-01  7.1056E-01  4.9539E+00 -7.7110E-03  7.0835E-03  5.3195E-03
   29  1.4000E-04 -1.9027E-01  8.8589E-01  5.4650E+00 -1.1017E-02  2.0128E-02  1.0372E-02
   31  1.5000E-04 -2.1381E-01  1.0795E+00  5.9891E+00 -1.5095E-02  3.8730E-02  1.8757E-02
   33  1.6000E-04 -2.3783E-01  1.2921E+00  6.5167E+00 -1.9996E-02  6.3995E-02  3.1738E-02
   35  1.7000E-04 -2.6205E-01  1.5173E+00  7.0482E+00 -2.5775E-02  9.7299E-02  5.0620E-02
   37  1.8000E-04 -2.8685E-01  1.7626E+00  7.5788E+00 -3.2514E-02  1.4036E-01  7.6605E-02
   39  1.9000E-04 -3.1149E-01  2.0222E+00  8.1097E+00 -4.0329E-02  1.9492E-01  1.1065E-01
   41  2.0000E-04 -3.3681E-01  2.2970E+00  8.6353E+00 -4.9349E-02  2.6265E-01  1.5337E-01
   43  2.1000E-04 -3.6129E-01  2.5879E+00  9.1519E+00 -5.9691E-02  3.4499E-01  2.0506E-01
   45  2.2000E-04 -3.8600E-01  2.8949E+00  9.6618E+00 -7.1427E-02  4.4315E-01  2.6573E-01
   47  2.3000E-04 -4.1029E-01  3.2141E+00  1.0161E+01 -8.4601E-02  5.5824E-01  3.3527E-01
   49  2.4000E-04 -4.3351E-01  3.5481E+00  1.0648E+01 -9.9240E-02  6.9154E-01  4.1357E-01
   51  2.5000E-04 -4.5582E-01  3.8942E+00  1.1122E+01 -1.1536E-01  8.4451E-01  5.0061E-01
   53  2.6000E-04 -4.7767E-01  4.2550E+00  1.1580E+01 -1.3297E-01  1.0188E+00  5.9653E-01
   55  2.7000E-04 -4.9885E-01  4.6265E+00  1.2027E+01 -1.5208E-01  1.2161E+00  7.0155E-01
   57  2.8000E-04 -5.1832E-01  5.0121E+00  1.2451E+01 -1.7266E-01  1.4379E+00  8.1594E-01
   59  2.9000E-04 -5.3628E-01  5.4117E+00  1.2835E+01 -1.9473E-01  1.6854E+00  9.3985E-01
   61  3.0000E-04 -5.5399E-01  5.8235E+00  1.3209E+01 -2.1829E-01  1.9593E+00  1.0733E+00
   63  3.1000E-04 -5.7035E-01  6.2440E+00  1.3570E+01 -2.4339E-01  2.2603E+00  1.2163E+00
   65  3.2000E-04 -5.8550E-01  6.6781E+00  1.3918E+01 -2.7002E-01  2.5890E+00  1.3685E+00
   67  3.3000E-04 -5.9947E-01  7.1191E+00  1.4261E+01 -2.9812E-01  2.9461E+00  1.5299E+00
   69  3.4000E-04 -6.1224E-01  7.5694E+00  1.4585E+01 -3.2760E-01  3.3327E+00  1.7001E+00
 71  3.5000E-04 -6.2460E-01  8.0300E+00  1.4896E+01 -3.5835E-01  3.7494E+00  1.8791E+00
 73  3.6000E-04 -6.3510E-01  8.4948E+00  1.5205E+01 -3.9026E-01  4.1969E+00  2.0670E+00
 75  3.7000E-04 -6.4496E-01  8.9686E+00  1.5494E+01 -4.2323E-01  4.6753E+00  2.2639E+00
 77  3.8000E-04 -6.5416E-01  9.4509E+00  1.5767E+01 -4.5715E-01  5.1844E+00  2.4700E+00
 79  3.9000E-04 -6.6229E-01  9.9375E+00  1.6036E+01 -4.9189E-01  5.7236E+00  2.6857E+00
 81  4.0000E-04 -6.7034E-01  1.0431E+01  1.6291E+01 -5.2736E-01  6.2922E+00  2.9112E+00
 83  4.1000E-04 -6.7756E-01  1.0931E+01  1.6526E+01 -5.6347E-01  6.8896E+00  3.1470E+00
 85  4.2000E-04 -6.8457E-01  1.1437E+01  1.6759E+01 -6.0013E-01  7.5155E+00  3.3937E+00
 87  4.3000E-04 -6.9093E-01  1.1948E+01  1.6979E+01 -6.3723E-01  8.1693E+00  3.6510E+00
 89  4.4000E-04 -6.9747E-01  1.2465E+01  1.7174E+01 -6.7464E-01  8.8503E+00  3.9219E+00
 91  4.5000E-04 -7.0376E-01  1.2989E+01  1.7365E+01 -7.1217E-01  9.5574E+00  4.2043E+00
 93  4.6000E-04 -7.1020E-01  1.3512E+01  1.7553E+01 -7.4965E-01  1.0289E+01  4.4993E+00
 95  4.7000E-04 -7.1622E-01  1.4043E+01  1.7710E+01 -7.8691E-01  1.1044E+01  4.8069E+00
 97  4.8000E-04 -7.2251E-01  1.4580E+01  1.7856E+01 -8.2381E-01  1.1819E+01  5.1266E+00
 99  4.9000E-04 -7.2891E-01  1.5118E+01  1.8000E+01 -8.6022E-01  1.2614E+01  5.4580E+00
101  5.0000E-04 -7.3577E-01  1.5659E+01  1.8127E+01 -8.9602E-01  1.3426E+01  5.8002E+00
103  5.1000E-04 -7.4298E-01  1.6208E+01  1.8223E+01 -9.3109E-01  1.4253E+01  6.1527E+00
105  5.2000E-04 -7.5094E-01  1.6760E+01  1.8317E+01 -9.6536E-01  1.5095E+01  6.5146E+00
107  5.3000E-04 -7.5834E-01  1.7311E+01  1.8408E+01 -9.9872E-01  1.5950E+01  6.8856E+00
109  5.4000E-04 -7.6640E-01  1.7871E+01  1.8463E+01 -1.0311E+00  1.6814E+01  7.2652E+00
111  5.5000E-04 -7.7556E-01  1.8433E+01  1.8501E+01 -1.0623E+00  1.7686E+01  7.6533E+00
113  5.6000E-04 -7.8511E-01  1.8995E+01  1.8537E+01 -1.0923E+00  1.8562E+01  8.0496E+00
115  5.7000E-04 -7.9475E-01  1.9559E+01  1.8565E+01 -1.1209E+00  1.9442E+01  8.4538E+00
117  5.8000E-04 -8.0490E-01  2.0129E+01  1.8552E+01 -1.1480E+00  2.0321E+01  8.8657E+00
119  5.9000E-04 -8.1562E-01  2.0702E+01  1.8533E+01 -1.1735E+00  2.1199E+01  9.2848E+00
121  6.0000E-04 -8.2643E-01  2.1275E+01  1.8512E+01 -1.1974E+00  2.2074E+01  9.7105E+00
123  6.1000E-04 -8.3804E-01  2.1851E+01  1.8471E+01 -1.2197E+00  2.2944E+01  1.0142E+01
125  6.2000E-04 -8.5026E-01  2.2436E+01  1.8386E+01 -1.2403E+00  2.3806E+01  1.0579E+01
127  6.3000E-04 -8.6205E-01  2.3023E+01  1.8300E+01 -1.2592E+00  2.4659E+01  1.1021E+01
129  6.4000E-04 -8.7428E-01  2.3608E+01  1.8213E+01 -1.2764E+00  2.5499E+01  1.1468E+01
131  6.5000E-04 -8.8701E-01  2.4194E+01  1.8110E+01 -1.2919E+00  2.6325E+01  1.1919E+01
133  6.6000E-04 -8.9966E-01  2.4788E+01  1.7978E+01 -1.3057E+00  2.7136E+01  1.2375E+01
135  6.7000E-04 -9.1225E-01  2.5380E+01  1.7844E+01 -1.3176E+00  2.7930E+01  1.2836E+01
137  6.8000E-04 -9.2519E-01  2.5971E+01  1.7711E+01 -1.3277E+00  2.8706E+01  1.3302E+01
139  6.9000E-04 -9.3799E-01  2.6562E+01  1.7564E+01 -1.3360E+00  2.9464E+01  1.3774E+01
141  7.0000E-04 -9.5074E-01  2.7162E+01  1.7389E+01 -1.3425E+00  3.0201E+01  1.4250E+01
143  7.1000E-04 -9.6374E-01  2.7760E+01  1.7211E+01 -1.3473E+00  3.0916E+01  1.4730E+01
145  7.2000E-04 -9.7703E-01  2.8354E+01  1.7034E+01 -1.3504E+00  3.1608E+01  1.5215E+01
147  7.3000E-04 -9.8930E-01  2.8950E+01  1.6851E+01 -1.3519E+00  3.2277E+01  1.5703E+01
149  7.4000E-04 -1.0021E+00  2.9552E+01  1.6635E+01 -1.3518E+00  3.2922E+01  1.6193E+01
151  7.5000E-04 -1.0150E+00  3.0155E+01  1.6415E+01 -1.3502E+00  3.3543E+01  1.6685E+01
153  7.6000E-04 -1.0277E+00  3.0755E+01  1.6201E+01 -1.3472E+00  3.4140E+01  1.7177E+01
155  7.7000E-04 -1.0396E+00  3.1352E+01  1.5993E+01 -1.3429E+00  3.4713E+01  1.7669E+01
157  7.8000E-04 -1.0519E+00  3.1957E+01  1.5744E+01 -1.3371E+00  3.5263E+01  1.8159E+01
159  7.9000E-04 -1.0647E+00  3.2563E+01  1.5489E+01 -1.3301E+00  3.5789E+01  1.8647E+01
161  8.0000E-04 -1.0765E+00  3.3167E+01  1.5240E+01 -1.3219E+00  3.6292E+01  1.9131E+01
163  8.1000E-04 -1.0881E+00  3.3766E+01  1.5001E+01 -1.3125E+00  3.6772E+01  1.9611E+01
165  8.2000E-04 -1.1002E+00  3.4372E+01  1.4725E+01 -1.3021E+00  3.7231E+01  2.0085E+01
167  8.3000E-04 -1.1121E+00  3.4980E+01  1.4440E+01 -1.2909E+00  3.7669E+01  2.0555E+01
169  8.4000E-04 -1.1235E+00  3.5586E+01  1.4161E+01 -1.2789E+00  3.8088E+01  2.1019E+01
171  8.5000E-04 -1.1348E+00  3.6189E+01  1.3888E+01 -1.2664E+00  3.8490E+01  2.1477E+01
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173  8.6000E-04 -1.1460E+00  3.6790E+01  1.3606E+01 -1.2532E+00  3.8875E+01  2.1929E+01
175  8.7000E-04 -1.1572E+00  3.7400E+01  1.3294E+01 -1.2397E+00  3.9247E+01  2.2374E+01
177  8.8000E-04 -1.1679E+00  3.8008E+01  1.2985E+01 -1.2257E+00  3.9605E+01  2.2811E+01
179  8.9000E-04 -1.1785E+00  3.8613E+01  1.2682E+01 -1.2115E+00  3.9951E+01  2.3240E+01
181  9.0000E-04 -1.1892E+00  3.9213E+01  1.2388E+01 -1.1971E+00  4.0287E+01  2.3660E+01
183  9.1000E-04 -1.1993E+00  3.9821E+01  1.2060E+01 -1.1826E+00  4.0615E+01  2.4070E+01
185  9.2000E-04 -1.2090E+00  4.0430E+01  1.1725E+01 -1.1681E+00  4.0937E+01  2.4471E+01
187  9.3000E-04 -1.2193E+00  4.1038E+01  1.1397E+01 -1.1539E+00  4.1257E+01  2.4862E+01
189  9.4000E-04 -1.2291E+00  4.1641E+01  1.1077E+01 -1.1399E+00  4.1575E+01  2.5245E+01
191  9.5000E-04 -1.2383E+00  4.2240E+01  1.0754E+01 -1.1264E+00  4.1894E+01  2.5617E+01
193  9.6000E-04 -1.2473E+00  4.2849E+01  1.0403E+01 -1.1135E+00  4.2216E+01  2.5980E+01
195  9.7000E-04 -1.2564E+00  4.3457E+01  1.0052E+01 -1.1012E+00  4.2542E+01  2.6333E+01
197  9.8000E-04 -1.2655E+00  4.4062E+01  9.7097E+00 -1.0895E+00  4.2873E+01  2.6676E+01
199  9.9000E-04 -1.2737E+00  4.4661E+01  9.3739E+00 -1.0786E+00  4.3213E+01  2.7007E+01
201  1.0000E-03 -1.2818E+00  4.5263E+01  9.0253E+00 -1.0686E+00  4.3563E+01  2.7325E+01
203  1.0100E-03 -1.2898E+00  4.5870E+01  8.6604E+00 -1.0594E+00  4.3926E+01  2.7629E+01
205  1.0200E-03 -1.2982E+00  4.6477E+01  8.2991E+00 -1.0512E+00  4.4303E+01  2.7918E+01
207  1.0300E-03 -1.3057E+00  4.7079E+01  7.9440E+00 -1.0441E+00  4.4696E+01  2.8192E+01
209  1.0400E-03 -1.3129E+00  4.7676E+01  7.5959E+00 -1.0381E+00  4.5105E+01  2.8448E+01
211  1.0500E-03 -1.3200E+00  4.8279E+01  7.2392E+00 -1.0334E+00  4.5533E+01  2.8687E+01
213  1.0600E-03 -1.3272E+00  4.8885E+01  6.8749E+00 -1.0300E+00  4.5980E+01  2.8908E+01
215  1.0700E-03 -1.3338E+00  4.9490E+01  6.5125E+00 -1.0280E+00  4.6447E+01  2.9111E+01
217  1.0800E-03 -1.3399E+00  5.0089E+01  6.1599E+00 -1.0273E+00  4.6936E+01  2.9294E+01
219  1.0900E-03 -1.3460E+00  5.0684E+01  5.8128E+00 -1.0280E+00  4.7447E+01  2.9458E+01
221  1.1000E-03 -1.3520E+00  5.1285E+01  5.4460E+00 -1.0301E+00  4.7982E+01  2.9602E+01
223  1.1100E-03 -1.3579E+00  5.1889E+01  5.0696E+00 -1.0335E+00  4.8541E+01  2.9727E+01
225  1.1200E-03 -1.3633E+00  5.2490E+01  4.7009E+00 -1.0384E+00  4.9124E+01  2.9831E+01
227  1.1300E-03 -1.3683E+00  5.3085E+01  4.3419E+00 -1.0446E+00  4.9731E+01  2.9916E+01
229  1.1400E-03 -1.3730E+00  5.3676E+01  3.9896E+00 -1.0522E+00  5.0360E+01  2.9980E+01
231  1.1500E-03 -1.3777E+00  5.4274E+01  3.6193E+00 -1.0613E+00  5.1014E+01  3.0024E+01
233  1.1600E-03 -1.3820E+00  5.4876E+01  3.2426E+00 -1.0719E+00  5.1690E+01  3.0048E+01
235  1.1700E-03 -1.3860E+00  5.5473E+01  2.8762E+00 -1.0838E+00  5.2389E+01  3.0050E+01
237  1.1800E-03 -1.3900E+00  5.6066E+01  2.5183E+00 -1.0971E+00  5.3111E+01  3.0031E+01
239  1.1900E-03 -1.3936E+00  5.6654E+01  2.1684E+00 -1.1118E+00  5.3853E+01  2.9992E+01
241  1.2000E-03 -1.3969E+00  5.7248E+01  1.7998E+00 -1.1276E+00  5.4617E+01  2.9931E+01
243  1.2100E-03 -1.4000E+00  5.7844E+01  1.4288E+00 -1.1445E+00  5.5398E+01  2.9850E+01
245  1.2200E-03 -1.4030E+00  5.8437E+01  1.0673E+00 -1.1626E+00  5.6197E+01  2.9749E+01
247  1.2300E-03 -1.4058E+00  5.9025E+01  7.1232E-01 -1.1817E+00  5.7012E+01  2.9627E+01
249  1.2400E-03 -1.4080E+00  5.9606E+01  3.6192E-01 -1.2017E+00  5.7840E+01  2.9484E+01
251  1.2500E-03 -1.4100E+00  6.0192E+01  3.2035E-03 -1.2227E+00  5.8681E+01  2.9320E+01
253  1.2600E-03 -1.4119E+00  6.0781E+01 -3.5943E-01 -1.2445E+00  5.9533E+01  2.9134E+01
255  1.2700E-03 -1.4137E+00  6.1368E+01 -7.1455E-01 -1.2671E+00  6.0395E+01  2.8925E+01
257  1.2800E-03 -1.4151E+00  6.1950E+01 -1.0653E+00 -1.2905E+00  6.1264E+01  2.8692E+01
259  1.2900E-03 -1.4160E+00  6.2524E+01 -1.4107E+00 -1.3144E+00  6.2138E+01  2.8435E+01
261  1.3000E-03 -1.4166E+00  6.3101E+01 -1.7571E+00 -1.3387E+00  6.3014E+01  2.8153E+01
263  1.3100E-03 -1.4174E+00  6.3686E+01 -2.1101E+00 -1.3633E+00  6.3890E+01  2.7845E+01
265  1.3200E-03 -1.4178E+00  6.4268E+01 -2.4572E+00 -1.3882E+00  6.4765E+01  2.7512E+01
267  1.3300E-03 -1.4179E+00  6.4846E+01 -2.8000E+00 -1.4131E+00  6.5636E+01  2.7154E+01
269  1.3400E-03 -1.4175E+00  6.5419E+01 -3.1364E+00 -1.4380E+00  6.6501E+01  2.6772E+01
271  1.3500E-03 -1.4168E+00  6.5990E+01 -3.4702E+00 -1.4629E+00  6.7360E+01  2.6365E+01
273  1.3600E-03 -1.4163E+00  6.6560E+01 -3.8104E+00 -1.4875E+00  6.8209E+01  2.5933E+01
```

```
275  1.3700E-03 -1.4156E+00  6.7146E+01 -4.1462E+00 -1.5120E+00  6.9047E+01  2.5478E+01
277  1.3800E-03 -1.4142E+00  6.7718E+01 -4.4775E+00 -1.5360E+00  6.9870E+01  2.5000E+01
279  1.3900E-03 -1.4128E+00  6.8285E+01 -4.8023E+00 -1.5596E+00  7.0678E+01  2.4498E+01
281  1.4000E-03 -1.4109E+00  6.8845E+01 -5.1225E+00 -1.5825E+00  7.1469E+01  2.3973E+01
283  1.4100E-03 -1.4091E+00  6.9415E+01 -5.4463E+00 -1.6046E+00  7.2241E+01  2.3426E+01
285  1.4200E-03 -1.4070E+00  6.9984E+01 -5.7662E+00 -1.6259E+00  7.2993E+01  2.2856E+01
287  1.4300E-03 -1.4044E+00  7.0549E+01 -6.0813E+00 -1.6461E+00  7.3724E+01  2.2264E+01
289  1.4400E-03 -1.4018E+00  7.1110E+01 -6.3920E+00 -1.6652E+00  7.4433E+01  2.1652E+01
291  1.4500E-03 -1.3987E+00  7.1664E+01 -6.6982E+00 -1.6832E+00  7.5118E+01  2.1018E+01
293  1.4600E-03 -1.3956E+00  7.2220E+01 -7.0021E+00 -1.6999E+00  7.5779E+01  2.0363E+01
295  1.4700E-03 -1.3921E+00  7.2780E+01 -7.3024E+00 -1.7154E+00  7.6414E+01  1.9688E+01
297  1.4800E-03 -1.3884E+00  7.3338E+01 -7.5999E+00 -1.7295E+00  7.7023E+01  1.8994E+01
299  1.4900E-03 -1.3844E+00  7.3892E+01 -7.8941E+00 -1.7421E+00  7.7605E+01  1.8280E+01
301  1.5000E-03 -1.3801E+00  7.4440E+01 -8.1850E+00 -1.7533E+00  7.8161E+01  1.7546E+01
```

(This history is abbreviated for illustrative purposes.)

E. INTEGRATION USING SIMPS1

The final step in the ELSHOK analysis of Case I is to use an appropriate integration algorithm to calculate a deflection history from the velocity information provided by the USLOB code. Simpson's 1/3 rule was chosen in this work and in this example, implemented in the form of SIMPS1.BAS which appears in appendix B.

The following is an entire output listing from this program. In the listing, the coordinate directions are defined as:

X = fore and aft
Y = vertical or normal to the hull
Z = athwartships

```
T =   0.0100   msec   DX =   0.000000  in.   DY =   0.000000  in.   DZ =  -0.000002
T =   0.0300   msec   DX =   0.000000  in.   DY =   0.000001  in.   DZ =  -0.000014
T =   0.0500   msec   DX =   0.000001  in.   DY =   0.000001  in.   DZ =  -0.000040
T =   0.0700   msec   DX =   0.000002  in.   DY =   0.000000  in.   DZ =  -0.000083
T =   0.0900   msec   DX =   0.000004  in.   DY =  -0.000004  in.   DZ =  -0.000144
T =   0.1100   msec   DX =   0.000006  in.   DY =  -0.000012  in.   DZ =  -0.000223
T =   0.1300   msec   DX =   0.000009  in.   DY =  -0.000026  in.   DZ =  -0.000322
T =   0.1500   msec   DX =   0.000013  in.   DY =  -0.000047  in.   DZ =  -0.000441
T =   0.1700   msec   DX =   0.000018  in.   DY =  -0.000075  in.   DZ =  -0.000581
T =   0.1900   msec   DX =   0.000023  in.   DY =  -0.000112  in.   DZ =  -0.000741
T =   0.2100   msec   DX =   0.000029  in.   DY =  -0.000157  in.   DZ =  -0.000920
T =   0.2300   msec   DX =   0.000036  in.   DY =  -0.000210  in.   DZ =  -0.001116
T =   0.2500   msec   DX =   0.000043  in.   DY =  -0.000271  in.   DZ =  -0.001329
T =   0.2700   msec   DX =   0.000050  in.   DY =  -0.000339  in.   DZ =  -0.001555
T =   0.2900   msec   DX =   0.000056  in.   DY =  -0.000414  in.   DZ =  -0.001793
T =   0.3100   msec   DX =   0.000063  in.   DY =  -0.000493  in.   DZ =  -0.002040
T =   0.3300   msec   DX =   0.000069  in.   DY =  -0.000577  in.   DZ =  -0.002295
T =   0.3500   msec   DX =   0.000074  in.   DY =  -0.000662  in.   DZ =  -0.002555
T =   0.3700   msec   DX =   0.000079  in.   DY =  -0.000748  in.   DZ =  -0.002819
T =   0.3900   msec   DX =   0.000082  in.   DY =  -0.000832  in.   DZ =  -0.003086
T =   0.4100   msec   DX =   0.000084  in.   DY =  -0.000913  in.   DZ =  -0.003354
T =   0.4300   msec   DX =   0.000085  in.   DY =  -0.000988  in.   DZ =  -0.003620
T =   0.4500   msec   DX =   0.000085  in.   DY =  -0.001057  in.   DZ =  -0.003883
T =   0.4700   msec   DX =   0.000084  in.   DY =  -0.001117  in.   DZ =  -0.004141
T =   0.4900   msec   DX =   0.000081  in.   DY =  -0.001167  in.   DZ =  -0.004392
T =   0.5100   msec   DX =   0.000077  in.   DY =  -0.001206  in.   DZ =  -0.004634
```

```
T =   0.5300   msec   DX =   0.000073  in.   DY =  -0.001233  in.   DZ =  -0.004864
T =   0.5500   msec   DX =   0.000067  in.   DY =  -0.001248  in.   DZ =  -0.005081
T =   0.5700   msec   DX =   0.000060  in.   DY =  -0.001251  in.   DZ =  -0.005283
T =   0.5900   msec   DX =   0.000053  in.   DY =  -0.001241  in.   DZ =  -0.005468
T =   0.6100   msec   DX =   0.000046  in.   DY =  -0.001219  in.   DZ =  -0.005634
T =   0.6300   msec   DX =   0.000038  in.   DY =  -0.001186  in.   DZ =  -0.005780
T =   0.6500   msec   DX =   0.000030  in.   DY =  -0.001144  in.   DZ =  -0.005903
T =   0.6700   msec   DX =   0.000021  in.   DY =  -0.001093  in.   DZ =  -0.006004
T =   0.6900   msec   DX =   0.000014  in.   DY =  -0.001035  in.   DZ =  -0.006079
T =   0.7100   msec   DX =   0.000006  in.   DY =  -0.000972  in.   DZ =  -0.006129
T =   0.7300   msec   DX =  -0.000001  in.   DY =  -0.000905  in.   DZ =  -0.006152
T =   0.7500   msec   DX =  -0.000008  in.   DY =  -0.000837  in.   DZ =  -0.006146
T =   0.7700   msec   DX =  -0.000014  in.   DY =  -0.000770  in.   DZ =  -0.006113
T =   0.7900   msec   DX =  -0.000019  in.   DY =  -0.000706  in.   DZ =  -0.006050
T =   0.8100   msec   DX =  -0.000024  in.   DY =  -0.000646  in.   DZ =  -0.005957
T =   0.8300   msec   DX =  -0.000027  in.   DY =  -0.000592  in.   DZ =  -0.005835
T =   0.8500   msec   DX =  -0.000030  in.   DY =  -0.000546  in.   DZ =  -0.005683
T =   0.8700   msec   DX =  -0.000032  in.   DY =  -0.000509  in.   DZ =  -0.005502
T =   0.8900   msec   DX =  -0.000032  in.   DY =  -0.000483  in.   DZ =  -0.005291
T =   0.9100   msec   DX =  -0.000032  in.   DY =  -0.000467  in.   DZ =  -0.005050
T =   0.9300   msec   DX =  -0.000031  in.   DY =  -0.000462  in.   DZ =  -0.004781
T =   0.9500   msec   DX =  -0.000029  in.   DY =  -0.000469  in.   DZ =  -0.004484
T =   0.9700   msec   DX =  -0.000025  in.   DY =  -0.000488  in.   DZ =  -0.004158
T =   0.9900   msec   DX =  -0.000022  in.   DY =  -0.000516  in.   DZ =  -0.003806
T =   1.0100   msec   DX =  -0.000017  in.   DY =  -0.000555  in.   DZ =  -0.003426
T =   1.0300   msec   DX =  -0.000012  in.   DY =  -0.000603  in.   DZ =  -0.003021
T =   1.0500   msec   DX =  -0.000006  in.   DY =  -0.000658  in.   DZ =  -0.002592
T =   1.0700   msec   DX =   0.000000  in.   DY =  -0.000719  in.   DZ =  -0.002141
T =   1.0900   msec   DX =   0.000006  in.   DY =  -0.000783  in.   DZ =  -0.001668
T =   1.1100   msec   DX =   0.000013  in.   DY =  -0.000850  in.   DZ =  -0.001175
T =   1.1300   msec   DX =   0.000019  in.   DY =  -0.000917  in.   DZ =  -0.000663
T =   1.1500   msec   DX =   0.000026  in.   DY =  -0.000982  in.   DZ =  -0.000135
T =   1.1700   msec   DX =   0.000032  in.   DY =  -0.001044  in.   DZ =   0.000408
T =   1.1900   msec   DX =   0.000037  in.   DY =  -0.001100  in.   DZ =   0.000965
T =   1.2100   msec   DX =   0.000043  in.   DY =  -0.001149  in.   DZ =   0.001533
T =   1.2300   msec   DX =   0.000047  in.   DY =  -0.001189  in.   DZ =   0.002111
T =   1.2500   msec   DX =   0.000051  in.   DY =  -0.001219  in.   DZ =   0.002697
T =   1.2700   msec   DX =   0.000054  in.   DY =  -0.001238  in.   DZ =   0.003290
T =   1.2900   msec   DX =   0.000056  in.   DY =  -0.001246  in.   DZ =   0.003887
T =   1.3100   msec   DX =   0.000057  in.   DY =  -0.001242  in.   DZ =   0.004486
T =   1.3300   msec   DX =   0.000057  in.   DY =  -0.001226  in.   DZ =   0.005085
T =   1.3500   msec   DX =   0.000056  in.   DY =  -0.001199  in.   DZ =   0.005682
T =   1.3700   msec   DX =   0.000054  in.   DY =  -0.001161  in.   DZ =   0.006274
T =   1.3900   msec   DX =   0.000051  in.   DY =  -0.001113  in.   DZ =   0.006860
T =   1.4100   msec   DX =   0.000047  in.   DY =  -0.001057  in.   DZ =   0.007437
T =   1.4300   msec   DX =   0.000042  in.   DY =  -0.000993  in.   DZ =   0.008004
T =   1.4500   msec   DX =   0.000037  in.   DY =  -0.000924  in.   DZ =   0.008558
T =   1.4700   msec   DX =   0.000030  in.   DY =  -0.000852  in.   DZ =   0.009098
T =   1.4900   msec   DX =   0.000023  in.   DY =  -0.000777  in.   DZ =   0.009621
T =   1.5100   msec   DX =   0.000015  in.   DY =  -0.000703  in.   DZ =   0.010127
T =   1.5300   msec   DX =   0.000007  in.   DY =  -0.000632  in.   DZ =   0.010612
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T =   1.5500   msec    DX =  -0.000001   in.    DY =  -0.000564   in.    DZ =   0.011075
T =   1.5700   msec    DX =  -0.000010   in.    DY =  -0.000503   in.    DZ =   0.011514
T =   1.5900   msec    DX =  -0.000019   in.    DY =  -0.000449   in.    DZ =   0.011927
T =   1.6100   msec    DX =  -0.000028   in.    DY =  -0.000403   in.    DZ =   0.012312
T =   1.6300   msec    DX =  -0.000036   in.    DY =  -0.000368   in.    DZ =   0.012667
T =   1.6500   msec    DX =  -0.000045   in.    DY =  -0.000344   in.    DZ =   0.012990
T =   1.6700   msec    DX =  -0.000053   in.    DY =  -0.000331   in.    DZ =   0.013282
T =   1.6900   msec    DX =  -0.000060   in.    DY =  -0.000329   in.    DZ =   0.013540
T =   1.7100   msec    DX =  -0.000067   in.    DY =  -0.000339   in.    DZ =   0.013764
T =   1.7300   msec    DX =  -0.000072   in.    DY =  -0.000359   in.    DZ =   0.013952
T =   1.7500   msec    DX =  -0.000077   in.    DY =  -0.000390   in.    DZ =   0.014104
T =   1.7700   msec    DX =  -0.000082   in.    DY =  -0.000430   in.    DZ =   0.014219
T =   1.7900   msec    DX =  -0.000085   in.    DY =  -0.000477   in.    DZ =   0.014297
T =   1.8100   msec    DX =  -0.000087   in.    DY =  -0.000531   in.    DZ =   0.014336
T =   1.8300   msec    DX =  -0.000088   in.    DY =  -0.000588   in.    DZ =   0.014337
T =   1.8500   msec    DX =  -0.000088   in.    DY =  -0.000648   in.    DZ =   0.014299
T =   1.8700   msec    DX =  -0.000087   in.    DY =  -0.000709   in.    DZ =   0.014222
T =   1.8900   msec    DX =  -0.000085   in.    DY =  -0.000769   in.    DZ =   0.014105
T =   1.9100   msec    DX =  -0.000083   in.    DY =  -0.000824   in.    DZ =   0.013950
T =   1.9300   msec    DX =  -0.000079   in.    DY =  -0.000875   in.    DZ =   0.013755
T =   1.9500   msec    DX =  -0.000075   in.    DY =  -0.000919   in.    DZ =   0.013522
T =   1.9700   msec    DX =  -0.000070   in.    DY =  -0.000954   in.    DZ =   0.013251
T =   1.9900   msec    DX =  -0.000064   in.    DY =  -0.000980   in.    DZ =   0.012943
T =   2.0100   msec    DX =  -0.000058   in.    DY =  -0.000995   in.    DZ =   0.012598
T =   2.0300   msec    DX =  -0.000051   in.    DY =  -0.000999   in.    DZ =   0.012218
T =   2.0500   msec    DX =  -0.000045   in.    DY =  -0.000991   in.    DZ =   0.011804
T =   2.0700   msec    DX =  -0.000038   in.    DY =  -0.000971   in.    DZ =   0.011355
T =   2.0900   msec    DX =  -0.000032   in.    DY =  -0.000940   in.    DZ =   0.010875
T =   2.1100   msec    DX =  -0.000025   in.    DY =  -0.000898   in.    DZ =   0.010363
T =   2.1300   msec    DX =  -0.000019   in.    DY =  -0.000846   in.    DZ =   0.009822
T =   2.1500   msec    DX =  -0.000014   in.    DY =  -0.000786   in.    DZ =   0.009252
T =   2.1700   msec    DX =  -0.000009   in.    DY =  -0.000718   in.    DZ =   0.008654
T =   2.1900   msec    DX =  -0.000005   in.    DY =  -0.000645   in.    DZ =   0.008030
T =   2.2100   msec    DX =  -0.000001   in.    DY =  -0.000568   in.    DZ =   0.007383
T =   2.2300   msec    DX =   0.000001   in.    DY =  -0.000489   in.    DZ =   0.006713
T =   2.2500   msec    DX =   0.000003   in.    DY =  -0.000410   in.    DZ =   0.006024
T =   2.2700   msec    DX =   0.000004   in.    DY =  -0.000333   in.    DZ =   0.005318
T =   2.2900   msec    DX =   0.000003   in.    DY =  -0.000260   in.    DZ =   0.004595
T =   2.3100   msec    DX =   0.000002   in.    DY =  -0.000193   in.    DZ =   0.003858
T =   2.3300   msec    DX =  -0.000000   in.    DY =  -0.000133   in.    DZ =   0.003111
T =   2.3500   msec    DX =  -0.000004   in.    DY =  -0.000082   in.    DZ =   0.002354
T =   2.3700   msec    DX =  -0.000008   in.    DY =  -0.000041   in.    DZ =   0.001589
T =   2.3900   msec    DX =  -0.000013   in.    DY =  -0.000011   in.    DZ =   0.000820
T =   2.4100   msec    DX =  -0.000019   in.    DY =   0.000007   in.    DZ =   0.000048
T =   2.4300   msec    DX =  -0.000026   in.    DY =   0.000013   in.    DZ =  -0.000724
T =   2.4500   msec    DX =  -0.000033   in.    DY =   0.000008   in.    DZ =  -0.001493
T =   2.4700   msec    DX =  -0.000041   in.    DY =  -0.000008   in.    DZ =  -0.002258
T =   2.4900   msec    DX =  -0.000049   in.    DY =  -0.000035   in.    DZ =  -0.003017
T =   2.5100   msec    DX =  -0.000057   in.    DY =  -0.000071   in.    DZ =  -0.003765
T =   2.5300   msec    DX =  -0.000065   in.    DY =  -0.000116   in.    DZ =  -0.004502
T =   2.5500   msec    DX =  -0.000074   in.    DY =  -0.000167   in.    DZ =  -0.005226
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T =   2.5700   msec   DX =  -0.000082  in.   DY =  -0.000223  in.   DZ =  -0.005933
T =   2.5900   msec   DX =  -0.000090  in.   DY =  -0.000282  in.   DZ =  -0.006623
T =   2.6100   msec   DX =  -0.000098  in.   DY =  -0.000342  in.   DZ =  -0.007294
T =   2.6300   msec   DX =  -0.000105  in.   DY =  -0.000402  in.   DZ =  -0.007942
T =   2.6500   msec   DX =  -0.000111  in.   DY =  -0.000458  in.   DZ =  -0.008566
T =   2.6700   msec   DX =  -0.000117  in.   DY =  -0.000510  in.   DZ =  -0.009166
T =   2.6900   msec   DX =  -0.000122  in.   DY =  -0.000555  in.   DZ =  -0.009739
T =   2.7100   msec   DX =  -0.000126  in.   DY =  -0.000592  in.   DZ =  -0.010281
T =   2.7300   msec   DX =  -0.000129  in.   DY =  -0.000620  in.   DZ =  -0.010794
T =   2.7500   msec   DX =  -0.000131  in.   DY =  -0.000638  in.   DZ =  -0.011274
T =   2.7700   msec   DX =  -0.000132  in.   DY =  -0.000644  in.   DZ =  -0.011720
T =   2.7900   msec   DX =  -0.000131  in.   DY =  -0.000639  in.   DZ =  -0.012133
T =   2.8100   msec   DX =  -0.000130  in.   DY =  -0.000623  in.   DZ =  -0.012510
T =   2.8300   msec   DX =  -0.000128  in.   DY =  -0.000595  in.   DZ =  -0.012850
T =   2.8500   msec   DX =  -0.000125  in.   DY =  -0.000556  in.   DZ =  -0.013155
T =   2.8700   msec   DX =  -0.000121  in.   DY =  -0.000507  in.   DZ =  -0.013421
T =   2.8900   msec   DX =  -0.000116  in.   DY =  -0.000449  in.   DZ =  -0.013648
T =   2.9100   msec   DX =  -0.000111  in.   DY =  -0.000384  in.   DZ =  -0.013837
T =   2.9300   msec   DX =  -0.000105  in.   DY =  -0.000313  in.   DZ =  -0.013987
T =   2.9500   msec   DX =  -0.000098  in.   DY =  -0.000238  in.   DZ =  -0.014097
T =   2.9700   msec   DX =  -0.000091  in.   DY =  -0.000161  in.   DZ =  -0.014166
T =   2.9900   msec   DX =  -0.000084  in.   DY =  -0.000085  in.   DZ =  -0.014196
T =   3.0100   msec   DX =  -0.000077  in.   DY =  -0.000010  in.   DZ =  -0.014185
T =   3.0300   msec   DX =  -0.000070  in.   DY =   0.000061  in.   DZ =  -0.014135
T =   3.0500   msec   DX =  -0.000063  in.   DY =   0.000126  in.   DZ =  -0.014046
T =   3.0700   msec   DX =  -0.000056  in.   DY =   0.000184  in.   DZ =  -0.013917
T =   3.0900   msec   DX =  -0.000050  in.   DY =   0.000233  in.   DZ =  -0.013751
T =   3.1100   msec   DX =  -0.000044  in.   DY =   0.000272  in.   DZ =  -0.013548
T =   3.1300   msec   DX =  -0.000039  in.   DY =   0.000299  in.   DZ =  -0.013309
T =   3.1500   msec   DX =  -0.000035  in.   DY =   0.000315  in.   DZ =  -0.013034
T =   3.1700   msec   DX =  -0.000031  in.   DY =   0.000320  in.   DZ =  -0.012726
T =   3.1900   msec   DX =  -0.000028  in.   DY =   0.000312  in.   DZ =  -0.012385
T =   3.2100   msec   DX =  -0.000027  in.   DY =   0.000294  in.   DZ =  -0.012011
T =   3.2300   msec   DX =  -0.000026  in.   DY =   0.000264  in.   DZ =  -0.011608
T =   3.2500   msec   DX =  -0.000026  in.   DY =   0.000225  in.   DZ =  -0.011176
T =   3.2700   msec   DX =  -0.000027  in.   DY =   0.000177  in.   DZ =  -0.010715
T =   3.2900   msec   DX =  -0.000030  in.   DY =   0.000123  in.   DZ =  -0.010231
T =   3.3100   msec   DX =  -0.000033  in.   DY =   0.000063  in.   DZ =  -0.009723
T =   3.3300   msec   DX =  -0.000037  in.   DY =   0.000000  in.   DZ =  -0.009192
T =   3.3500   msec   DX =  -0.000042  in.   DY =  -0.000064  in.   DZ =  -0.008642
T =   3.3700   msec   DX =  -0.000047  in.   DY =  -0.000127  in.   DZ =  -0.008076
T =   3.3900   msec   DX =  -0.000054  in.   DY =  -0.000188  in.   DZ =  -0.007492
T =   3.4100   msec   DX =  -0.000060  in.   DY =  -0.000244  in.   DZ =  -0.006897
T =   3.4300   msec   DX =  -0.000068  in.   DY =  -0.000294  in.   DZ =  -0.006290
T =   3.4500   msec   DX =  -0.000075  in.   DY =  -0.000336  in.   DZ =  -0.005673
T =   3.4700   msec   DX =  -0.000083  in.   DY =  -0.000368  in.   DZ =  -0.005050
T =   3.4900   msec   DX =  -0.000091  in.   DY =  -0.000390  in.   DZ =  -0.004422
T =   3.5100   msec   DX =  -0.000098  in.   DY =  -0.000400  in.   DZ =  -0.003791
T =   3.5300   msec   DX =  -0.000105  in.   DY =  -0.000399  in.   DZ =  -0.003159
T =   3.5500   msec   DX =  -0.000112  in.   DY =  -0.000387  in.   DZ =  -0.002530
T =   3.5700   msec   DX =  -0.000119  in.   DY =  -0.000362  in.   DZ =  -0.001905
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T =   3.5900   msec   DX =  -0.000125   in.    DY =  -0.000327   in.    DZ =  -0.001286
T =   3.6100   msec   DX =  -0.000130   in.    DY =  -0.000281   in.    DZ =  -0.000677
T =   3.6300   msec   DX =  -0.000134   in.    DY =  -0.000227   in.    DZ =  -0.000079
T =   3.6500   msec   DX =  -0.000138   in.    DY =  -0.000165   in.    DZ =   0.000508
T =   3.6700   msec   DX =  -0.000140   in.    DY =  -0.000097   in.    DZ =   0.001078
T =   3.6900   msec   DX =  -0.000142   in.    DY =  -0.000024   in.    DZ =   0.001632
T =   3.7100   msec   DX =  -0.000142   in.    DY =   0.000050   in.    DZ =   0.002167
T =   3.7300   msec   DX =  -0.000142   in.    DY =   0.000125   in.    DZ =   0.002681
T =   3.7500   msec   DX =  -0.000140   in.    DY =   0.000197   in.    DZ =   0.003174
T =   3.7700   msec   DX =  -0.000137   in.    DY =   0.000266   in.    DZ =   0.003643
T =   3.7900   msec   DX =  -0.000134   in.    DY =   0.000330   in.    DZ =   0.004086
T =   3.8100   msec   DX =  -0.000130   in.    DY =   0.000387   in.    DZ =   0.004501
T =   3.8300   msec   DX =  -0.000124   in.    DY =   0.000434   in.    DZ =   0.004889
T =   3.8500   msec   DX =  -0.000118   in.    DY =   0.000472   in.    DZ =   0.005246
T =   3.8700   msec   DX =  -0.000112   in.    DY =   0.000499   in.    DZ =   0.005571
T =   3.8900   msec   DX =  -0.000105   in.    DY =   0.000514   in.    DZ =   0.005865
T =   3.9100   msec   DX =  -0.000097   in.    DY =   0.000518   in.    DZ =   0.006125
T =   3.9300   msec   DX =  -0.000089   in.    DY =   0.000509   in.    DZ =   0.006351
T =   3.9500   msec   DX =  -0.000081   in.    DY =   0.000489   in.    DZ =   0.006543
T =   3.9700   msec   DX =  -0.000073   in.    DY =   0.000458   in.    DZ =   0.006699
T =   3.9900   msec   DX =  -0.000065   in.    DY =   0.000418   in.    DZ =   0.006819
T =   4.0100   msec   DX =  -0.000058   in.    DY =   0.000369   in.    DZ =   0.006905
T =   4.0300   msec   DX =  -0.000051   in.    DY =   0.000313   in.    DZ =   0.006953
T =   4.0500   msec   DX =  -0.000044   in.    DY =   0.000252   in.    DZ =   0.006966
T =   4.0700   msec   DX =  -0.000038   in.    DY =   0.000187   in.    DZ =   0.006944
T =   4.0900   msec   DX =  -0.000032   in.    DY =   0.000121   in.    DZ =   0.006884
T =   4.1100   msec   DX =  -0.000028   in.    DY =   0.000056   in.    DZ =   0.006789
T =   4.1300   msec   DX =  -0.000024   in.    DY =  -0.000007   in.    DZ =   0.006659
T =   4.1500   msec   DX =  -0.000021   in.    DY =  -0.000065   in.    DZ =   0.006494
T =   4.1700   msec   DX =  -0.000020   in.    DY =  -0.000118   in.    DZ =   0.006294
T =   4.1900   msec   DX =  -0.000019   in.    DY =  -0.000162   in.    DZ =   0.006062
T =   4.2100   msec   DX =  -0.000019   in.    DY =  -0.000197   in.    DZ =   0.005796
T =   4.2300   msec   DX =  -0.000020   in.    DY =  -0.000222   in.    DZ =   0.005500
T =   4.2500   msec   DX =  -0.000022   in.    DY =  -0.000236   in.    DZ =   0.005174
T =   4.2700   msec   DX =  -0.000025   in.    DY =  -0.000238   in.    DZ =   0.004818
T =   4.2900   msec   DX =  -0.000029   in.    DY =  -0.000228   in.    DZ =   0.004436
T =   4.3100   msec   DX =  -0.000034   in.    DY =  -0.000207   in.    DZ =   0.004027
T =   4.3300   msec   DX =  -0.000039   in.    DY =  -0.000175   in.    DZ =   0.003593
T =   4.3500   msec   DX =  -0.000045   in.    DY =  -0.000132   in.    DZ =   0.003135
T =   4.3700   msec   DX =  -0.000052   in.    DY =  -0.000081   in.    DZ =   0.002657
T =   4.3900   msec   DX =  -0.000058   in.    DY =  -0.000021   in.    DZ =   0.002158
T =   4.4100   msec   DX =  -0.000065   in.    DY =   0.000044   in.    DZ =   0.001641
T =   4.4300   msec   DX =  -0.000072   in.    DY =   0.000114   in.    DZ =   0.001109
T =   4.4500   msec   DX =  -0.000079   in.    DY =   0.000187   in.    DZ =   0.000562
T =   4.4700   msec   DX =  -0.000086   in.    DY =   0.000260   in.    DZ =   0.000005
T =   4.4900   msec   DX =  -0.000093   in.    DY =   0.000331   in.    DZ =  -0.000563
T =   4.5100   msec   DX =  -0.000099   in.    DY =   0.000399   in.    DZ =  -0.001138
T =   4.5300   msec   DX =  -0.000104   in.    DY =   0.000462   in.    DZ =  -0.001719
T =   4.5500   msec   DX =  -0.000109   in.    DY =   0.000517   in.    DZ =  -0.002303
T =   4.5700   msec   DX =  -0.000113   in.    DY =   0.000565   in.    DZ =  -0.002888
T =   4.5900   msec   DX =  -0.000116   in.    DY =   0.000602   in.    DZ =  -0.003472
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T =   4.6100   msec   DX =  -0.000118   in.   DY =   0.000629   in.   DZ =  -0.004053
T =   4.6300   msec   DX =  -0.000119   in.   DY =   0.000644   in.   DZ =  -0.004629
T =   4.6500   msec   DX =  -0.000120   in.   DY =   0.000648   in.   DZ =  -0.005196
T =   4.6700   msec   DX =  -0.000119   in.   DY =   0.000640   in.   DZ =  -0.005754
T =   4.6900   msec   DX =  -0.000117   in.   DY =   0.000620   in.   DZ =  -0.006299
T =   4.7100   msec   DX =  -0.000114   in.   DY =   0.000590   in.   DZ =  -0.006831
T =   4.7300   msec   DX =  -0.000110   in.   DY =   0.000550   in.   DZ =  -0.007345
T =   4.7500   msec   DX =  -0.000105   in.   DY =   0.000501   in.   DZ =  -0.007841
T =   4.7700   msec   DX =  -0.000100   in.   DY =   0.000445   in.   DZ =  -0.008318
T =   4.7900   msec   DX =  -0.000093   in.   DY =   0.000383   in.   DZ =  -0.008772
T =   4.8100   msec   DX =  -0.000086   in.   DY =   0.000318   in.   DZ =  -0.009202
T =   4.8300   msec   DX =  -0.000079   in.   DY =   0.000251   in.   DZ =  -0.009603
T =   4.8500   msec   DX =  -0.000071   in.   DY =   0.000184   in.   DZ =  -0.009987
T =   4.8700   msec   DX =  -0.000062   in.   DY =   0.000120   in.   DZ =  -0.010337
T =   4.8900   msec   DX =  -0.000054   in.   DY =   0.000060   in.   DZ =  -0.010658
T =   4.9100   msec   DX =  -0.000045   in.   DY =   0.000005   in.   DZ =  -0.010948
T =   4.9300   msec   DX =  -0.000037   in.   DY =  -0.000042   in.   DZ =  -0.011205
T =   4.9500   msec   DX =  -0.000028   in.   DY =  -0.000079   in.   DZ =  -0.011429
T =   4.9700   msec   DX =  -0.000020   in.   DY =  -0.000107   in.   DZ =  -0.011618
T =   4.9900   msec   DX =  -0.000013   in.   DY =  -0.000124   in.   DZ =  -0.011771
T =   5.0100   msec   DX =  -0.000006   in.   DY =  -0.000129   in.   DZ =  -0.011888
T =   5.0300   msec   DX =   0.000000   in.   DY =  -0.000123   in.   DZ =  -0.011969
T =   5.0500   msec   DX =   0.000006   in.   DY =  -0.000105   in.   DZ =  -0.012012
T =   5.0700   msec   DX =   0.000011   in.   DY =  -0.000076   in.   DZ =  -0.012017
T =   5.0900   msec   DX =   0.000014   in.   DY =  -0.000037   in.   DZ =  -0.011985
T =   5.1100   msec   DX =   0.000017   in.   DY =   0.000012   in.   DZ =  -0.011914
T =   5.1300   msec   DX =   0.000019   in.   DY =   0.001498   in.   DZ =  -0.011806
T =   5.1500   msec   DX =   0.000019   in.   DY =   0.001561   in.   DZ =  -0.011659
T =   5.1700   msec   DX =   0.000019   in.   DY =   0.001629   in.   DZ =  -0.011474
T =   5.1900   msec   DX =   0.000018   in.   DY =   0.001700   in.   DZ =  -0.011252
T =   5.2100   msec   DX =   0.000016   in.   DY =   0.001771   in.   DZ =  -0.010992
T =   5.2300   msec   DX =   0.000013   in.   DY =   0.001842   in.   DZ =  -0.010696
T =   5.2500   msec   DX =   0.000009   in.   DY =   0.001909   in.   DZ =  -0.010363
T =   5.2700   msec   DX =   0.000004   in.   DY =   0.001971   in.   DZ =  -0.009996
T =   5.2900   msec   DX =  -0.000001   in.   DY =   0.002027   in.   DZ =  -0.009594
T =   5.3100   msec   DX =  -0.000007   in.   DY =   0.002074   in.   DZ =  -0.009160
T =   5.3300   msec   DX =  -0.000013   in.   DY =   0.002112   in.   DZ =  -0.008694
T =   5.3500   msec   DX =  -0.000019   in.   DY =   0.002139   in.   DZ =  -0.008198
T =   5.3700   msec   DX =  -0.000026   in.   DY =   0.002155   in.   DZ =  -0.007674
T =   5.3900   msec   DX =  -0.000032   in.   DY =   0.002160   in.   DZ =  -0.007122
T =   5.4100   msec   DX =  -0.000038   in.   DY =   0.002152   in.   DZ =  -0.006544
T =   5.4300   msec   DX =  -0.000044   in.   DY =   0.002133   in.   DZ =  -0.005943
T =   5.4500   msec   DX =  -0.000050   in.   DY =   0.002104   in.   DZ =  -0.005318
T =   5.4700   msec   DX =  -0.000055   in.   DY =   0.002064   in.   DZ =  -0.004674
T =   5.4900   msec   DX =  -0.000059   in.   DY =   0.002015   in.   DZ =  -0.004010
T =   5.5100   msec   DX =  -0.000063   in.   DY =   0.001959   in.   DZ =  -0.003329
T =   5.5300   msec   DX =  -0.000066   in.   DY =   0.001898   in.   DZ =  -0.002634
T =   5.5500   msec   DX =  -0.000068   in.   DY =   0.001832   in.   DZ =  -0.001927
T =   5.5700   msec   DX =  -0.000069   in.   DY =   0.001764   in.   DZ =  -0.001209
T =   5.5900   msec   DX =  -0.000069   in.   DY =   0.001696   in.   DZ =  -0.000483
T =   5.6100   msec   DX =  -0.000068   in.   DY =   0.001630   in.   DZ =   0.000248
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 T =    5.6300   msec    DX =  -0.000066  in.    DY =    0.001567  in.    DZ =    0.000983
 T =    5.6500   msec    DX =  -0.000063  in.    DY =    0.001510  in.    DZ =    0.001720
 T =    5.6700   msec    DX =  -0.000059  in.    DY =    0.001461  in.    DZ =    0.002456
 T =    5.6900   msec    DX =  -0.000054  in.    DY =    0.001420  in.    DZ =    0.003189
 T =    5.7100   msec    DX =  -0.000049  in.    DY =    0.001389  in.    DZ =    0.003917
 T =    5.7300   msec    DX =  -0.000042  in.    DY =    0.001369  in.    DZ =    0.004638
 T =    5.7500   msec    DX =  -0.000035  in.    DY =    0.001360  in.    DZ =    0.005350
 T =    5.7700   msec    DX =  -0.000027  in.    DY =    0.001363  in.    DZ =    0.006051
 T =    5.7900   msec    DX =  -0.000019  in.    DY =    0.001377  in.    DZ =    0.006737
 T =    5.8100   msec    DX =  -0.000010  in.    DY =    0.001403  in.    DZ =    0.007408
 T =    5.8300   msec    DX =  -0.000001  in.    DY =    0.001439  in.    DZ =    0.008061
 T =    5.8500   msec    DX =   0.000008  in.    DY =    0.001485  in.    DZ =    0.008694
 T =    5.8700   msec    DX =   0.000017  in.    DY =    0.001539  in.    DZ =    0.009305
 T =    5.8900   msec    DX =   0.000025  in.    DY =    0.001599  in.    DZ =    0.009892
 T =    5.9100   msec    DX =   0.000034  in.    DY =    0.001665  in.    DZ =    0.010454
 T =    5.9300   msec    DX =   0.000042  in.    DY =    0.001734  in.    DZ =    0.010990
 T =    5.9500   msec    DX =   0.000049  in.    DY =    0.001804  in.    DZ =    0.011497
 T =    5.9700   msec    DX =   0.000056  in.    DY =    0.001873  in.    DZ =    0.011974
 T =    5.9900   msec    DX =   0.000062  in.    DY =    0.001939  in.    DZ =    0.012420
TMAX(X) =  3.7100    msec  DMAX(X) =  -0.000142   in.
TMAX(Y) =  5.3900    msec  DMAX(Y) =   0.002160   in.
TMAX(Z) =  1.8300    msec  DMAX(Z) =   0.014337   in.
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